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July 17, 2004

To: Cheryl Yuhas and the Suborbital Workshop Participants

Following are the notes and products from all of your work last week. This package contains a tremendous amount of valuable material – we were amazed by your extraordinary productivity!

Cheers,

Cindy, John & Yumiko

Suborbital Science Missions of the Future Workshop
July 13-15, 2004

Opening Remarks

Cheryl's Opening Remarks

- Welcome
- I'm looking forward to a productive workshop… coming up with a lot of good ideas
- The suborbital program is being restructured to try to move into the future
- I've partnered with aeronautics… to come up with new technologies… to find out what will best serve our objectives in the future
- We are working around our six science focus areas in our Earth Science Directorate
- We're looking at the second half of the road map
- I would like to challenge you to think of things you haven't thought of before
- We will then hand them off to our aeronautics engineers…
- We want to identify the best technologies to invest in for the future

Mike Luther's Remarks

- Good morning… thanks for coming
- This is an important endeavor to the Enterprise
- I'll lead off with the mandatory Mission and Vision… set the stage… remind you that in spite of all the things you may have heard, this is still our mission and vision
- We're here to re-address the strategy of the suborbital program in the context of science – everything we do here ought to have a very strong science focus
- Hopefully we can make it sustainable financially and politically if we have that strong science basis
- We have been evolving… looking at the sub-questions that define our roadmaps against which we measure our progress…
- We are focusing our energy around these six science focus areas
- Making very god progress… Not only at articulating our program, but moving towards a full management structure around these areas
- We conduct periodic reviews… on about an annual basis… there are special topics… we are cross-cutting the budget… and organizing integrated product development teams…
- All of these are consistent with what our sponsors want us to do
- We see those efforts continuing to move forward

- This picture (slide) is a reminder of how far we're come
- We now operate about 18 spacecraft and about 80 sensors in cooperation with our partners
- About ten years ago… we supported the community on an average of about 1 or 2 spacecraft at a time
- We've dramatically changed the character of the program

Mike Luther's Remarks (cont.)

Opening Remarks

- We now have the ability to make measurements on any number of scales… something man has not had the capability to do in history
- This is a wonderful testament to the ability of the people in this room and beyond

- We have not revolutionized the suborbital program
- What you all are challenged to do is help us think about how we can move to a commensurate mobilization of the suborbital program… consistent with what we've been able to do in the space

- Currently we utilize largely two-dimensional sensors…
- The logical next step is to move more heavily to measurements that will give us a more three-dimensional view of the planet
- There are some new advances and technologies we want to pursue
- As we go forward we think we'll be relying on multidimensional and active systems…

- What we're challenging you to think about in this workshop is how we can move forward… how we can achieve a commensurate revolution for the next generation of suborbital capabilities

- These capabilities need to be comprehensive, coordinated and sustainable
- Comprehensive – science based… across all science disciplines… as well as the applications
- Coordinated – across partnerships
- Sustainable – we need to ensure that we can make the argument in the social-political court that this is in fact an integral part of the system… that is *has* to be done to do the job correctly

- What are those capabilities?
- UAV's, airships, long-durational balloons… in some cases piloted aircraft…
- How can our measurements be enhanced by these capabilities?

- As far as the transition activity goes… a lot of things we're going to talk about can be used by others…
- As we transition the science codes together a lot of what we're doing here will influence the other sciences…

- If we build it from a science base up, that make sit easier to deliver the message to our sponsors… to make it sustainable…

Opening Remarks

Mike Luther's Remarks (cont.)

Q&A:

Q: Significant achievements we've made in our space-based resources have required significant resources… Is the Agency willing to step up to the tune of a few hundred million dollars to fund it?

- A: It's incumbent upon us to make the case to our sponsors…. We need to make the compelling case that these capabilities will enable demonstrable improvements to the science community and ultimately to the taxpayer… We need to be able to articulate a scientific argument
- I share your concern… Is it going to be easy? No. If we do something incremental that looks like more of the same, we will not be successful… "We're going to change the way we think… the way we implement…" That's what we need to say

Q: If the resources don't match the requirement… if we lost capability … my response would be to play defense to maintain payload and hours… The ability to do science has a great deal to do with how many pounds we can get in the air and ho long we can keep it there... Are we really talking about expanding our capabilities here?

- A: I understand… There's lots of ways to think about it… What we're asking you to do is take a leap ahead five years or so… Don't think about next year or the year after… Ask yourselves, "Where do I want to be?"
- If we only play defense… We haven't done spectacularly at growing our capability under the current set of strategies and assets… At some point, we've got to change these assets out… We can start now… get our act together… make a paradigm shift… or we can just keep driving the same truck… I worry it's going to break down on us
- I would argue that we ought to be here to work offensively… Unless we can develop a sound science basis for new capabilities we're doomed to being "drug along"…

Q: Why does NASA spend millions of dollars on UAV development when the military spends billions of dollars on the same things?

- A: Earth science spends very little money on development… We leverage capabilities and apply them to our science… We made it clear that we wanted no part in UAV development… The Agency has invested in UAV's fairly heavily in the past… Our investment levels have tapered significantly… The military has increased theirs…
- We have an ongoing debate within the Agency… What is the goal of the investment? Why? We had to bring forward the science rationale…
- What we want to come out of here is a broad consensus on what the requirements are for a new generation of technologies…
- What the military is developing will help us, but won't be exactly what we need

Opening Remarks

Mike Luther's Remarks (cont.)

Q: Based on your experience, what lessons would you like us to keep in mind as we develop new technologies (thinking of it more as a complete system)?

- A: The shift that we're going through is "Yes, we're going to have a lot of assets out there… even the space-based systems…" We need to take a hint of what we tried to do with space-based missions… our operational approach… but be more distributed… more end-to-end
- Not everything has to go into one box somewhere in the world… We can put it at a number of locations… make it available through the internet… Distributed architectures and standards… increased accessibility…

Q: Seems we should make sure part of the investment is in data management…

- A: Absolutely… We want the intellectual capability of the science to be virtually around that site… that has to come into play… It may be clear that there is some particular site that is ideal to be the caretaker

Q: We need to get on the roadmap the training of the next generation of researchers… We're falling a little short…

- A: Absolutely… With the advent of education being an element of our vision and mission… the addition of the education Office… early investigative programs… There is also a new program of scholarships… We're trying to jump start this very quickly… on a skill-set basis…

Q: Have the earth scientists identified questions that can be researched from the LDP or ULDP platforms?

- A: The question is: How do we want to *manage* technologies… That's a perfect example of where there's a synergy of certain technologies with our desires… We have to work for the benefit of both organizations…
- We have a lot of people who are very excited about those opportunities… to bring them together and think about them in a new way…
- We could use those technologies to do earth analog activities for another planet… to accomplish the same things that we could do here on earth…

Comment: If there's a commitment to the maintenance of current capabilities, that makes the transition from defense to offense a lot easier.

- A: The challenge is to find out what we think the goal is… then how to close the gap

Science Focus Work Group Products

Atmospheric Composition

Attendees

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- Note: Mike Kurylo (Lead)

Atmospheric Composition

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- Assessment of the potential for future major depletion of Arctic O_3
- Strat. O_3 recovery in changing climate; assessment of trop. O_3 trends & mechanisms
- Validation of changes in trop. and strat. O_3, water vapor, aerosols and potential impacts of future changes on climate & atmospheric chemistry
- Evaluations of feedbacks between aerosols, O_3, H_2O, & climate
- Evaluation of chemistry/climate interactions with multi-decadal simulations of the strat & trop. Quantify mechanisms for evolution of trop O_3.
- Operational predictions linking O_3 & aerosols with climate & air quality

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Linkage to climate & cloud physics (climate roadmap), hydrological cycle (water and energy cycle), weather (weather roadmap), carbon cycle (carbon cycle roadmap)

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

<u>High resolution (vertical, horizontal, and temporal), simultaneous observations measured over long range are necessary to elucidate physical and chemical processes. These fine scale observations are extendable to the global scale satellite observations.</u>

- Strat ozone chemistry: profiling of source gases, water, aerosols, and temperature in the mid-latitudes and polar regions in the UT/LS.
- Trop pollutants: profiling of pollutants and particles and their source emissions on regional to hemispheric scales from near the surface to the tropopause region.
- Water vapor and total water: profiling of water from the mid-troposphere to the lower stratosphere from the tropics into the mid-latitudes.
- Clouds & aerosols: profiling of cloud and clear sky environments (optical, composition, and microphysical parameters) to examine chemical variability of aerosols and direct and indirect chemical and radiative effects of clouds and aerosols.

Atmospheric Composition – Cloud & Aerosol

<u>Critical Observation</u>: Study transformations of aerosols and gases in cloud systems for:

- Convective systems – 100's of km (Costa Rica, So. Florida, Central US)
- Sea breeze cloud formation -100's of km (US coastal)
- Marine stratiform – 100's of km (California coastal)
- Contrails (Central US in air traffic regions) & ship tracks (ocean) – 100's of km
- Synoptic scale systems & Fronts – 1000's of km (Central US)
- Cirrus outflow – 1000's of km (tropics, So. Florida, Central US)

- Profiling of cloud and clear sky environments (optical, composition, and microphysical parameters) to examine variability of aerosols and direct and indirect chemical and radiative effects of clouds and aerosols.

- Investigate fundamental microphysics of cloud drop formation and evolution by looking at inflow/outflow through these systems to see the transformations. For example, we would look at inflow into cumulus convection in the boundary layer and lower troposphere and the outflow in the mid-to-upper troposphere. Aerosols and pollutants are modified by these convective systems as they are lofted into UT/LS. These flights may occur in severe convective environments (i.e., strong vertical wind shear, severe lightning).

- Formation flying (4 aircraft): 3 in-situ sampling aircraft to sample in-flow region, out-flow region, and convective core, and a high altitude remote sensing aircraft (near tropopause).

- Pre-programmed flight scenario with re-tasking during the mission. Over the horizon communication control of aircraft by ground base. Near real-time re-tasking based upon observations from remote sensing platform. Observations of these aerosol & cloud events synergistic with satellite platforms.

Atmospheric Composition – Cloud & Aerosol

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

<u>Measurements (simultaneous):</u>
Water vapor, total water
Temperature, Pressure, Winds
Ozone
Lightning
Aerosols & cloud particles
- Chemical composition
- Number, size, volume
- Habit
- Extinction & absorption

Source gases & tracers
- Hydrocarbons
- Formaldehyde
- HNO_3
- NO_y
- CO_2, CO
- HCl
- CH_3I
- Sulfur species (e.g., H_2SO_4, SO_2)

Radicals
- NO, NO_2
- OH, HO_2
- RO_2

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Primary question in the ESE strategic plan.

Explicitly state the advantage of using a suborbital platform for this measurement.

- High spatial and temporal resolution, overlap with and extension of satellite observations. The measurements aboard a suborbital system can be chosen to be much more comprehensive than the planned and operational satellite instruments. Improved targeting of atmospheric phenomena (e.g., Lagrangian sampling). Instruments can be calibrated in the air and on the ground pre and post-flight. Measurement flexibility and greater capability for instrument upgrades.

Identify other cross-cutting areas impacted by this observation.

- Climate change, hydrological cycle, weather

Atmospheric Composition – Cloud & Aerosol

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- All instruments have own computers and data storage. Aircraft performance (altitude, latitude, longitude, time, attitude) required.

  <u>Measurements (remote):</u>
  Water vapor (lidar1)
  Temperature (lidar2, uwave3, dropsonde4), Pressure, Winds (9.5 Doppler radar5)
  Ozone (lidar2, FTIR6, UV-Vis7)
  Lightning (optical8)
  Aerosols & cloud particles (ice water content) (lidar2, radar9: 95 Ghz)

  <u>Remote Sensing platform:</u>
  9 instruments
  total weight = 2000 lbs. (current individual instruments range from 50-500 lbs.)
  total volume = 150 cu. ft.
  environmental conditions – nadir windows for lidar (16 in. diameter), UV-Vis requires a relatively uninhibited horizon view, side window ports for microwave and FTIR, nadir windows for radars.
  total power = 10 kW

  <u>Measurements (in-situ inflow and outflow regions; * convective core - UAHumV):</u>
  Water vapor(1)*, total water(2)*, isotopic water
  Temperature*, Pressure*, Winds* (3)
  Ozone (4)
  Lightning* (5)
  Aerosols* & cloud particles* (6-11)
  Chemical composition
  Number, size, volume
  Habit
  Extinction & absorption
  Source gases & tracers (12-21)
  Hydrocarbons (2)
  Formaldehyde (1)
  HNO_3(1)
  NO_y*
  CO_2*, CO*
  HCl
  CH_3I*

Sulfur species (e.g., H_2SO_4, SO_2)
Radicals (22-24)
NO, NO_2
OH, HO_2
RO_2

<u>In-situ inflow/outflow platforms (simultaneous, high frequency observations)</u>
24 instruments
total weight = 2800 lbs. (current individual instruments range from 35-400 lbs.)
total volume = 180 cu. ft.
environmental conditions – free stream sampling, no pressurization, some air flow scoops and venting, instrument cooling is a major issue for tropospheric sampling – active temperature control may be necessary.
total power = 10 kW

<u>In-situ convective core (UAHumV) platform (simultaneous, high frequency observations)</u>
14 instruments
total weight = 1600 lbs. (current individual instruments range from 35-400 lbs.)
total volume = 100 cu. ft.
environmental conditions – free stream sampling, no pressurization, some air flow scoops and venting, instrument cooling is a major issue for tropospheric sampling – active temperature control may be necessary.
total power = 8 kW

Atmospheric Composition – Cloud & Aerosol

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Locations:
  Convective systems – tropics, So. Florida, Central US
  Sea breeze cloud formation -US coastal
  Marine stratiform – California coastal
  Contrails (Central US in air traffic regions) & ship tracks (ocean)
  Synoptic scale systems & Fronts –Central US
  Cirrus outflow –tropics, So. Florida, Central US

- Altitude:
  Remote: FL 400-600
  In-situ in-flow: near surface to FL200
  In-situ out-flow: FL 200-600
  In-situ UAHumV: FL 200-500
- Range: 6000 km
- 0.4 < Mach number < 0.7
- Endurance: 24 hours
- Season: winter, spring, summer, fall
- Frequency: daily flight capability with up to 3 flights per week. 4 week campaigns
- g-loading: mountain wave and convection induced turbulence common. UAHumV aircraft must essentially be an “armored” UAV capable of sustaining severe turbulence (50 m/s downdrafts), lightning strikes, and large hail.
- Cross wind takeoff capability of 25 kts, 35 kts total.

Communication needs such as real-time data or instrument control

- Real time communication for re-tasking aircraft in mid-air as meteorological, cloud, and near real time radar imagery evolves. Over the horizon capability is essential. Minimum 9600 baud for instruments.

Atmospheric Composition – Cloud & Aerosol

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "cycle-in-the-life" of the mission.

1) Instrument preparation
2) Initial mission planning
3) Mission programming or pilot briefing
4) Instrument upload
5) Takeoff
6) Time-to-target
7) Real-time data transmission & radar imagery leading to aircraft formation re-tasking
8) Return to base
9) Instrument download
10) Instrument & aircraft servicing
11) Data analysis
12) Mission objective revisions based upon flight results

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

1) Takeoff from base.
2) Remote platform ascends to maximum altitude
3) All aircraft proceed towards predicted cloud systems
4) In-situ platforms adjust altitudes to: inflow region (near surface < 10 kft. for in-flow platform), outflow (mid-troposphere 10-55 kft for outflow platform), convective core (25-55 kft for convective core, UAHumV platform), and near tropopause (remote sensing platform).
5) In-situ aircraft are vectored on multiple passes across or through the cloud system (as determined by remote platform observations and radar). Altitudes are adjusted amongst in-situ to capture cloud features.
6) Descent to base.

Identify any special or unique platform or mission issues

- Capability to release a tracer chemical in the boundary layer near the bottom of the in-flow region and trace its transport through the cloud system to the out-flow region.

- Ground-based radar system for identifying possible cloud system targets and for directing aircraft to such systems.

- Terrain following radar necessary for boundary layer in-situ platform.

Atmospheric Composition – Cloud & Aerosol

Summarize the key elements of the mission concept for this measurement.

- A mission to study the sources, evolution, distribution and impact of tropospheric aerosols and clouds. The main elements of this mission are:

  1) Moderate range (6,000 km),
  2) 24-hour duration,
  3) Multiple coordinated platforms with real time command capability,
  4) Heavy lift (24 instruments - 2800 lbs.),
  5) High duty cycle (3 flights per week over a month long campaign), and
  6) An armored UAV for flying in severe storms.

Atmospheric Composition – Stratospheric 0zone

<u>Critical Observation</u>: Stratospheric ozone chemistry: profiling of source gases, water, aerosols, and temperature in the mid-latitudes and polar regions in the UT/LS.

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- <u>Recovery of the stratospheric ozone layer.</u> Will the ozone layer (i.e., Antarctic ozone hole, Arctic ozone levels, mid-latitude) recover to pre-1980 levels? How will climate change interact with the expected decrease of ODS?

- <u>Measurements (simultaneous):</u>
    - Water vapor, total water
    - Temperature, Pressure, Winds
    - Ozone
    - Aerosols & Polar stratospheric clouds
    - Source gases & tracers
        - Halocarbons
        - N_2O, CH_4, SF_6, CO_2, CO
        - COS, Isotopes
    - Reservoir species
        - HNO_3
        - HCl
        - $ClONO_2$
    - Radicals
        - ClOx
        - BrO
        - NOx
        - HOx
        - IO
    - UV-Vis

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Primary question in the ESE strategic plan.

Atmospheric Composition – Stratospheric 0zone

Explicitly state the advantage of using a suborbital platform for this measurement.

- High spatial and temporal resolution, overlap with and extension of satellite observations.
- The measurements aboard a suborbital system can be chosen to be much more comprehensive than the planned and operational satellite instruments.
- Improved targeting of atmospheric phenomena (e.g., Lagrangian sampling).
- Instruments can be calibrated in the air and on the ground pre and post-flight.
- Measurement flexibility and greater capability for instrument upgrades.

Identify other cross-cutting areas impacted by this observation.

- Climate change.

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports):

- All instruments have own computers and data storage.
- Aircraft performance data (altitude, latitude, longitude, time, attitude) required by the instruments.
- Experimenters need easy access to instruments, and instruments will probably be off-loaded from aircraft after each flight.
- All instruments weight, volume, and power estimates are based upon current capabilities.

21 In-situ instruments
total weight = 2500 lbs. (current individual instruments range from 35-400 lbs.)
total volume = 150 cu. ft.
environmental conditions – **free stream sampling**, no pressurization, some air flow scoops and venting
total power = 10 kW

6 Remote sensing instruments: 2 lidars, 1 FTIR, 2 microwave, 1 UV-Vis
total weight = 1000 lbs. (current individual instruments range from 35-500 lbs.)
total volume = 75 cu. ft.
environmental conditions – both zenith and nadir windows for lidar (16 in. diameter), UV-Vis requires a relatively uninhibited horizon view, side window ports for microwave and FTIR.
total power = 10 kW

Atmospheric Composition – Stratospheric 0zone

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics:

- Location: basing flexibility to provide access from mid-latitudes to either pole
- Altitude: **FL 300-700**
- Range**: 24,000 km**
- Speed: 0.4 < Mach number < 0.7
- Endurance: **2-5 days**
- Season: winter (polar night, extremely cold in Antarctic vortex in mid-winter, 180 K), spring, summer, fall
- Frequency**: 48-hour turnaround. ~1 flight every week during a campaign.** Campaigns will last approximately 1 month (2-3 flights/campaign). A Northern experiment with campaigns in Dec., Jan., Feb., and Mar. of a particular winter. A Southern experiment with campaigns in Jul., Aug., Sep., Oct. (not necessarily the same year as the Northern campaign).
- Reliability: The mission requires 1000 flight hours over a 4-month period without major interruptions.
- Basing: mid-to-low latitudes in the Northern hemisphere for the Northern campaign and in the Southern hemisphere for the Southern campaign.
- g-loading: mountain wave induced turbulence common in polar regions, aircraft must be able to sustain nominal turbulence comparable to ER-2 (3 g's).
- Takeoff capability: cross wind max of 20 kts, 30 kts total.

Communication needs such as real-time data or instrument control

- Real time communication for re-tasking aircraft in mid-air as meteorological, PSC, and chemical forecasts evolve. **Over the horizon capability is essential.** Minimum 9600 baud for instruments.

Atmospheric Composition – Stratospheric 0zone

Mission Concept: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "cycle-in-the-life" of the mission.

1. Instrument preparation
2. Initial mission planning
3. Mission programming or pilot briefing
4. Instrument upload
5. Takeoff
6. Time-to-target
7. Real-time data transmission & updated forecasts leading to plane re-tasking
8. Return to base
9. Instrument download
10. Instrument & aircraft servicing
11. Data analysis
12. Mission objective revisions based upon flight results

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

1. Takeoff from base (e.g., Dryden).
2. Ascend to cruise altitude at 2500 ft./min.
3. Proceed northward towards polar vortex
4. Vertical profiles from maximum altitude to below tropopause every 10° of latitude ~ 2000 ft./minute. Spiral descents.
5. Cross the polar vortex boundary
6. Aircraft targeted on PSC in high Arctic
7. Lagrangian sampling downstream of PSC
8. Race-track sampling of PSCs over Scandinavian mountains (some turbulence expected). Temperatures are approximately 190 K. Wind speeds of 100 kts.
9. Re-cross polar vortex on return, spiral descent vertical profiles every 10° of latitude ~ 2000 ft./minute.
10. Descent to base

Identify any special or unique platform or mission issues

- Crenellation flights – aircraft flies at two alternate levels (e.g., FL650 and FL450) switching altitudes every 20-30 minutes. May choose upper altitude to be maximum altitude.

- Isentropic flight – aircraft adjusts altitude in order to remain on a fixed isentrope [$\square = T\ (P/1000)^{3.5}$].

Atmospheric Composition – Stratospheric 0zone

Summarize the key elements of the mission concept for this measurement.

- A mission to study stratospheric ozone recovery as ozone depleting substances decrease and the effects of climate change on this recovery from the mid-latitudes to the pole. The main elements of this mission are: 1) long range (24,000 km), 2) long duration (2-5 days), 3) high altitude (70,000 feet), 4) heavy lift (27 instruments - 3500 lbs.), and 5) high reliability.

- An alternative scenario for this mission might be to split the payload into in-situ and remote sensing instruments and to fly these payloads in formation on two separate aircraft.

Atmospheric Composition – Tropospheric 0zone

Critical Observation: Tropospheric pollution and air quality: profiling of pollutants and particles and their source emissions on regional to hemispheric scales from near the surface to the tropopause region. Determine where plumes of pollution are transported and how they evolve.

- Formation flying (4 aircraft): Boundary in-situ, mid-trop in-situ, upper-trop in-situ, high altitude remote sensing (near tropopause).

- Pre-programmed scenario with re-tasking during the mission. Over the horizon communication control of aircraft by ground base. Near real-time re-tasking based upon observations from remote sensing platform. Following plume events over several days and over 10,000 km. Observations of these plume events synergistic with geostationary platform UV-Vis and IR observations.

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Sources of tropospheric pollution and the evolution of that pollution (including biomass burning). Photochemistry of troposphere, interaction of clouds and chemistry, anthropogenic and natural aerosols interaction with clouds and chemistry.

    Measurements (simultaneous):
    Water vapor, total water
    Temperature, Pressure, Winds
    Ozone
    Aerosols & cloud particles
        Chemical composition
        Number, size, volume
        Habit
        Extinction & absorption
    Source gases & tracers
        Hydrocarbons
        Formaldehyde
        CO_2, CO
        Sulfur species (e.g., SO_2)
    Radicals
        NO, NO_2
        OH, HO_2
        RO_2
    UV-Vis
    IR flux

Atmospheric Composition – Tropospheric 0zone

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Primary question in the ESE strategic plan.

Explicitly state the advantage of using a suborbital platform for this measurement.

- High spatial and temporal resolution, overlap with and extension of satellite observations. The measurements aboard a suborbital system can be chosen to be much more comprehensive than the planned and operational satellite instruments. Improved targeting of atmospheric phenomena (e.g., Lagrangian sampling). Instruments can be calibrated in the air and on the ground pre and post-flight. Measurement flexibility and greater capability for instrument upgrades. Quick response for geophysical phenomena such as volcanic plumes.

Identify other cross-cutting areas impacted by this observation.

- Climate change, hydrological cycle, carbon, weather

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- All instruments have own computers and data storage. Aircraft performance (altitude, latitude, longitude, time, attitude) required.

Remote Sensing platform:
7 instruments
total weight = 1600 lbs. (current individual instruments range from 50-500 lbs.)
total volume = 100 cu. ft.
environmental conditions – nadir windows for lidar (16 in. diameter), UV-Vis requires a relatively uninhibited horizon view, side window ports for microwave and FTIR.
total power = 10 kW

Atmospheric Composition – Tropospheric 0zone

In-situ platforms (simultaneous, high frequency observations)
21 instruments
total weight = 2500 lbs. (current individual instruments range from 35-400 lbs.)
total volume = 150 cu. ft.
environmental conditions – **free stream sampling**, no pressurization, some air flow scoops and venting, instrument cooling is a major issue for tropospheric sampling – active temperature control may be necessary.
total power = 10 kW

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

Location: basing flexibility to provide: 1) access from Eastern Pacific ocean across US into North Atlantic, 2) access from Africa across Atlantic and across South America (biomass burning and megacities), and 3) access from Eurasia across the Pacific into North America.

Altitude:
Remote: FL 400-600
In-situ: near surface to FL600
Range: 15,000 km
0.4 < Mach number < 0.7
Endurance: 2-4 days
Season: winter, spring, summer, fall
Frequency: 48 hour turnaround. ~1 flight per week during a campaign.
g-loading: mountain wave and convection induced turbulence, aircraft must be able to sustain nominal turbulence (3 g's).
Cross wind takeoff capability of 20 kts, 30 kts total.

Communication needs such as real-time data or instrument control

- Real time communication for re-tasking aircraft in mid-air as meteorological, cloud, and chemical forecasts evolve.
- Over the horizon capability is essential.
- Minimum 9600 baud for instruments.

Atmospheric Composition – Tropospheric 0zone

Mission Concept: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "cycle-in-the-life" of the mission.

1. Instrument preparation
2. Initial mission planning
3. Mission programming or pilot briefing
4. Instrument upload
5. Takeoff
6. Time-to-target
7. Real-time data transmission & updated forecasts leading to aircraft formation re-tasking
8. Return to base
9. Instrument download
10. Instrument & aircraft servicing
11. Data analysis
12. Mission objective revisions based upon flight results

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

1. Takeoff from base (e.g., Dryden).
2. Remote platform ascends to maximum altitude
3. In-situ platforms take off & fly wing-tip to wing-tip (within 1 km in clear air).
4. All aircraft proceed towards initial plume location
5. In-situ platforms adjust altitude to: 1) near surface < 10 kft., 2) mid-troposphere (10-35 kft), and 3) upper-trop (25-55 kft). Aircraft are co-located in latitude/longitude.
6. Aircraft are vectored on multiple passes across the plume (as determined by remote platform observations). Altitudes are adjusted amongst in-situ to capture plume features.
7. Descent to base (may be different from takeoff location).

Identify any special or unique platform or mission issues

- Crenellation flights – aircraft fly at alternate levels (e.g., FL650 and FL450) switching altitudes every 20-30 minutes. May choose upper altitude to be maximum altitude.

- Terrain following radar necessary for in-situ platforms.

Atmospheric Composition – Tropospheric 0zone

Summarize the key elements of the mission concept for this measurement.

- A mission to study the sources, evolution, and distribution of tropospheric pollutants. Evaluate the effects of regional pollution on the global atmosphere and assess the impact of global chemistry on regional air quality. The main elements of this mission are: 1) long range (15,000 km), 2) long duration (2-4 days), 3) multiple coordinated platforms with real time command capability, 4) heavy lift (21 instruments - 2500 lbs.), and 5) high reliability.

Atmospheric Composition – Water Vapor & Total Water

Critical Observation: Water vapor and total water: Profiling of water from the mid-troposphere to the lower stratosphere from the tropics into the mid-latitudes. What controls UT/LS water and how will that impact climate change feedbacks?

- 2 platforms: A remote sensing platform in the stratosphere and an in-situ platform below in UT/LS.

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

Measurements (**simultaneous**):
Water vapor, total water, water isotopes
Temperature, Pressure, Winds
Ozone
Aerosols & cirrus cloud particles
- number, volume, mass
- composition
- habit

Trace gases
- Formaldehyde
- Methyl iodide
- N_2O, CH_4, SF_6, CO_2, CO
- HNO3
- HCl

IR radiance

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Primary question in the ESE strategic plan. Forcing question (1), Variability question (4), and Response question (4).

Explicitly state the advantage of using a suborbital platform for this measurement.

- **High spatial and temporal resolution, overlap with and extension of satellite observations.** The measurements aboard a suborbital system can be chosen to be much more comprehensive than the planned and operational satellite instruments. Improved targeting of atmospheric phenomena (e.g., Lagrangian sampling). Instruments can be calibrated in the air and on the ground pre and post-flight. Measurement flexibility and greater capability for instrument upgrades.

Identify other cross-cutting areas impacted by this observation.

- Climate change. Water and energy cycle, weather.

Atmospheric Composition – Water Vapor & Total Water

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- All instruments have own computers and data storage. Aircraft performance data (altitude, latitude, longitude, time, attitude) required by the instruments. Experimenters need easy access to instruments, and instruments will probably be off-loaded from aircraft after each flight. **All instruments weight, volume, and power estimates are based upon current capabilities.**

- <u>Measurements (remote sensing)</u>
  Water vapor (lidar-1, FTIR-5)
  Temperature (microwave-2, dropsondes-4, FTIR-5), Pressure, Winds
  Ozone (lidar -3)
  Aerosols & cirrus cloud particles (lidar -3)
  IR radiance (FTIR-5)
  5 Remote sensing instruments: 2 lidars, 1 FTIR, 1 microwave, 1 dropsonde
  - total weight = 1200 lbs. (current individual instruments range from 35-500 lbs.)
  - total volume = 80 cu. ft.
  - environmental conditions – nadir window for lidar (16 in. diameter), side window ports for microwave and FTIR.
  - total power = 8 kW

- <u>Measurements (**simultaneous**):</u>
  Water vapor (1), total water(2), water isotopes (3)
  Temperature, Pressure, Winds (4)
  Ozone (5)
  Aerosols & cirrus cloud particles (6-10)
    - number, volume, mass
    - composition
    - habit

  Trace gases (11-16)
    - Formaldehyde
    - Methyl iodide
    - N_2O, CH_4, SF_6, CO_2, CO
    - HNO_3
    - HCl

Atmospheric Composition – Water Vapor & Total Water

IR radiance (1)
17 In-situ instruments
- total weight = 1800 lbs. (current individual instruments range from 35-400 lbs.)
- total volume = 120 cu. ft.
- environmental conditions – **free stream sampling**, no pressurization, some air flow scoops and venting
- total power = 8 kW

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- <u>Location:</u> basing flexibility to provide access to sub-tropics and tropics over extended longitudinal range (e.g., Eastern Pacific to Indian Ocean along equator)
- <u>Altitude:</u> **FL 300-700**
- <u>Range:</u> **40,000 km**
- 0.4 < <u>Mach number</u> < 0.7
- <u>Endurance:</u> 3**-5 days**
- <u>Season:</u> winter, spring, summer, fall
- <u>Frequency:</u> **~2-3 flights per month.** Campaigns will last approximately 1 month (2-3 flights/campaign). 4 campaigns per year.
- <u>Reliability:</u> Needs to be able to conduct the 2-3 flights over the 1-month campaign period.
- <u>Basing:</u> mid-to-low latitudes in the Northern hemisphere.
- <u>g-loading:</u> Aircraft must be able to sustain nominal turbulence comparable to ER-2 (3 g's).
- <u>Environmental:</u> Temperatures near tropical tropopause typically near 180K. ***<u>Aircraft need to have radar capability for avoiding severe storms.</u>***
- <u>Takeoff capability:</u> cross wind max of 20 kts, 30 kts total.

Communication needs such as real-time data or instrument control

- Real time communication for re-tasking aircraft in mid-air as meteorological, cloud, and chemical forecasts evolve. **Over the horizon capability is essential.** Minimum 9600 baud for instruments.

Atmospheric Composition – Water Vapor & Total Water

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "cycle-in-the-life" of the mission.

1. Instrument preparation
2. Initial mission planning
3. Mission programming or pilot briefing
4. Instrument upload
5. Takeoff
6. Real-time data transmission & updated forecasts leading to plane re-tasking
7. Return to base
8. Instrument download
9. Instrument & aircraft servicing
10. Data analysis
11. Mission objective revisions based upon flight results

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

1. Takeoff from base (e.g., Dryden).
2. Remote platform ascends to cruise altitude. In-situ platform ascends to max altitude at 2500 ft./min
3. Proceed southward to equator.
4. In situ vertical profiles from maximum altitude to 12 km every 10˚ of latitude ~ 2000 ft./minute. Spiral descents.
5. Both aircraft turn westward at equator.
6. In situ vertical profiles from maximum altitude to 12 km every 10˚ of longitude along equator ~ 2000 ft./minute. Spiral descents.
7. If remote sensing platform detects sub-visible cirrus, the in-situ platform would be vectored into the cloud.
8. Turn back eastward in Indian Ocean. Repeat profiling on eastward bound leg.
9. Turn northward at 120˚W and return to base.

Identify any special or unique platform or mission issues

- Crenellation flights – aircraft flies at two alternate levels (e.g., FL650 and FL450) switching altitudes every 20-30 minutes. May choose upper altitude to be maximum altitude.
- Isentropic flight – aircraft adjusts altitude in order to remain on a fixed isentrope [$\theta = T\ (P/1000)^{3.5}$].
- Would circumnavigate the globe on at least 1 flight per campaign.

Summarize the key elements of the mission concept for this measurement.

- A mission to study water in the tropical tropopause layer. The main elements of this mission are: 1) extreme range (40,000 km), 2) long duration (2-5 days), 3) high altitude (70,000 feet), 4) heavy lift (17 instruments - 1800 lbs.), and 5) high reliability.

Atmospheric Composition

Key Messages

- Tailored improvements to UAV developments currently underway at orders of magnitude higher funding levels (i.e., Global Hawk)
  - Revolution is disruptive
  - Maintains continuity with existing capabilities

- Expansion of existing envelope rather than definition of entirely new envelope with limited funding
  - Increased range, duration, payload capacity, geophysical performance
  - Ensure that science drives UAV technology modifications rather than aeronautic technology seeking scientific justification

- Parallel / well-funded instrument development program is essential. Maintain and evolve core research and analysis

- Maintain complete observation system synergy (satellite – suborbital – ground – models)
  - Unique elements to each
  - High complementarity
  - Sensor web requires all components

- Show us some concrete results from this workshop
  - Not just paper
  - We've been here before

- Explore national and international cooperation and partnerships

Carbon Cycle, Ecosystems, and Biogeochemistry

Attendees

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- Note: Matt Fladeland (Lead)

Carbon Cycle, Ecosystems, and Biogeochemistry

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- Southern Ocean Carbon Program
- Physiology and Functional Groups – high spatial resolution; diurnal studies
- New Ocean Carbon / Coastal Event Observations
- High-Resolution Atmospheric CO_2

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Disturbance assessment, monitoring and recovery
- Particulate/black carbon – land-air interface
- Lower troposphere measurements (100m and down) – resolve deposition models
- Boundary layer, tropospheric measurements
- Instabilities in carbon sources and sinks – ie. permafrost
- Wetlands and surface inundation studies – CH_4
- Global land use change
- Coastal event observations and land-ocean interface – resolving horizontal rather than vertical resolution (improved spatial and temporal resolution), multiple sensor integration
- Comprehensive oceanic survey of carbon cycling
- Process studies on inorganic component of soil carbon

Carbon Cycle, Ecosystems, and Biogeochemistry

Critical Science Questions

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

- Time series measurements of surface to atmosphere gas flux
    - Co2 and O2 measurements – separate out land vs. ocean fluxes
    - Vertical resolution of column Co2 (OCO validation)

- Vegetation structure/composition, height measurements, ocean surface characterization (ie. roughness, surface height)
    - Improved characterization of biomass (terrestrial & oceanic) using hyperspectral imagery, LIDAR, Radar, passive microwave, Interferometric radar (p, x, band – veg), (ku – ocean surface), (wide-swath ocean altimeter validation)

- Quanitify atmospheric particulate matter (eg. black carbon) and aerosols originating from biomass combustion

- Observations of the lower troposphere to constrain boundary layer

- Observations of permafrost condition and change using radar

- Fluorescence measurements over land and ocean to discern functional groups and physiology

- Sea surface salinity measurements for ocean circulation (Aquarius validation)

- Hurricane impacts affects on carbon cycle (plankton blooms, sea-air co2 exchange, coastal)

- Coastal event observations and land-ocean interface – resolving horizontal rather than vertical resolution (improved spatial and temporal resolution), multiple sensor integration

Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations

Critical Observation: **Coastal ocean observations:** Resolving horizontal and vertical resolution (improved spatial and temporal resolution), multiple sensor integration

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

Science Questions:

- How do coastal blooms change over time and space and what is their composition?
- How can we measure estuarine condition?
- How are nutrients consumed and released in the coastal zone, and how does this impact the carbon cycle?
- How well can we quantify submerged aquatic vegetation and coral reefs?

Observations:

- Quantify biomass by measuring aspects of aquatic organisms in the coastal zone. (350nm-1000nm)
- Sea surface temperature and profile (1/10th of degree)
- Vertical profile of biomass
- Sea surface roughness
- Sea surface salinity

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Supports the stated goal of reducing uncertainties in the fluxes and coastal sea dynamics

Explicitly state the advantage of using a suborbital platform for this measurement.

- High frequency measurements to resolve temporal variation
- High resolution in space time and spectra.

Identify other cross-cutting areas impacted by this observation.

- This mission can be flown in tandem with the co2 flux mission

Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Hypersprectral Sensor – 350nm-1000nm – 25kg, 100w
- Tunable Laser diode – 25kg, 100w
- TIR Sensor – 8-12micron – 25kg, 100w
- Microwave for Salinity (details needed – see Aquarius)
- Scatterometer (Ku band) for roughness
- Deployable underwater vehicle
    - Salinity
    - Temperature at depth
    - Optical properties of water column
    - Chemical pro

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

Location:
- Areas of interest: North America Coast, Tropics
- From coast to 50-200km (dependent on depth of continental shelf)

Altitude:
- Approx. 40,000ft to avoid commercial traffic
  Spatial resolutions from 1m-10m
  Constrained by power of lidar

Endurance:
- 24-hour missions for each season
- Measurements every 20m

Platforms:
- Integrating measurements with underwater vehicles

Communication needs such as real-time data or instrument control

- Over-the-horizon command and control and data telemetry
- Near realtime communication with underwater vehicles, buoys to allow for flexibility in tasking
- 20 Mbs

Carbon Cycle, Ecosystems, and Biogeochemistry – Coastal Ocean Observations

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

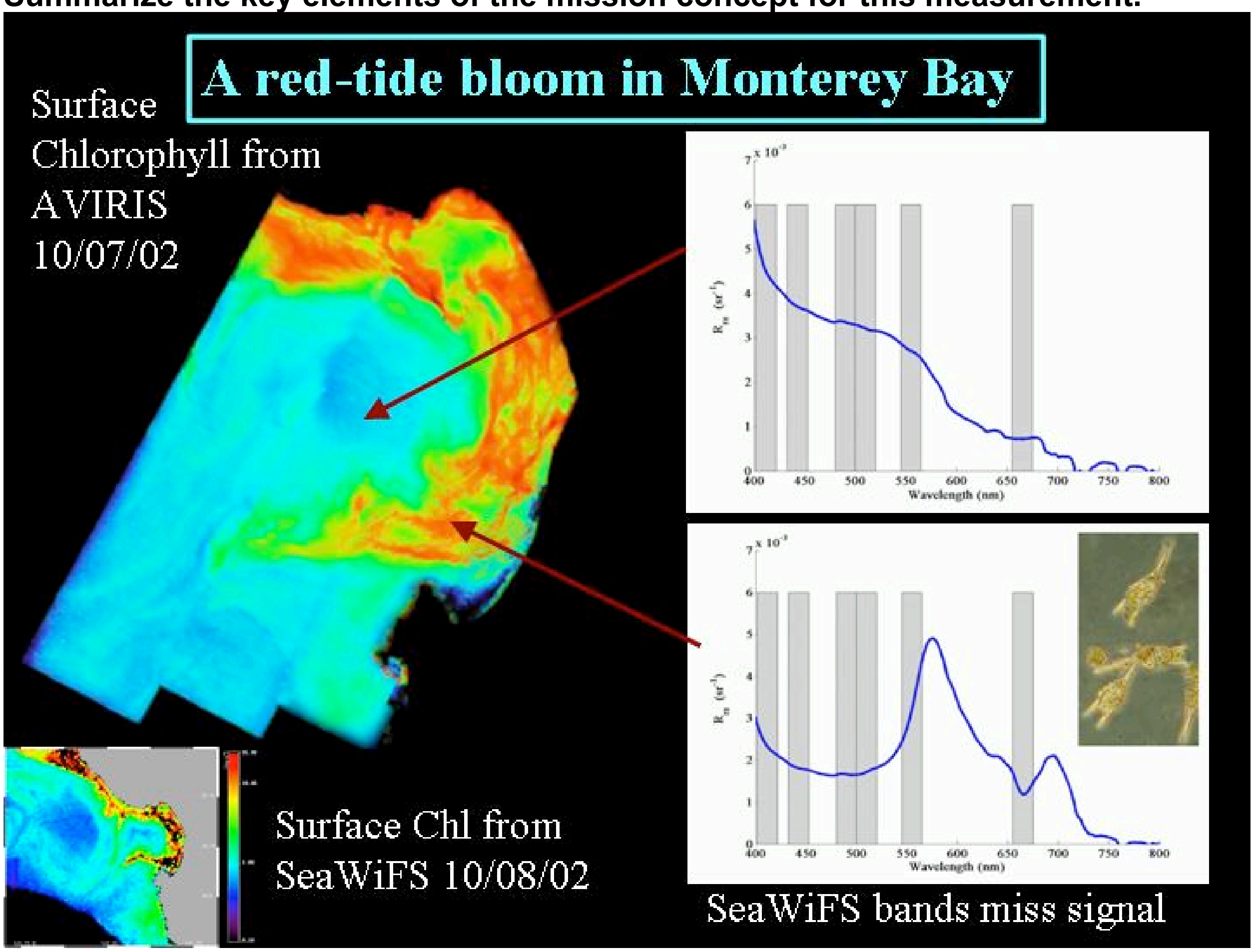
- Cue mission from MODIS/VIIRS ocean color measurements or in situ buoys or following cyclone/hurricane events.
- Aircraft will be deployed before the bloom to observe and measure the development and waning.
- Underwater vehicles will be deployed from air or land.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Loitering mission for bay or estuary; transects for larger coastal regions

Identify any special or unique platform or mission issues
(no input)

Summarize the key elements of the mission concept for this measurement.



Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment

<u>Critical Observation</u>: Active Fire, emissions, and plume assessment

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Atmospheric chemistry
- Thermal intensity time-series
- Plume composition, volume, albedo, and particle size distribution
- Fuel type and quality

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Understanding the influence of disturbance on carbon cycle dynamics

Explicitly state the advantage of using a suborbital platform for this measurement.

- Loitering capabilities
- Dangerous & Dirty plume measurements

Identify other cross-cutting areas impacted by this observation.

- Atmospheric composition focus area would benefit from a better understanding of chemical constituents of fire plumes resulting from different fuels under different intensities of fire

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Isotope ratio mass spectrometers, Gas chromotographer, Non-Dispersive IR Analyzer
    - 50-100kg
    - Accurate IMU – tbd
    - 3D windfield at 10hz or better
    - height and velocity from interferometer?
    - Mind the engine exhaust
    - Ancillary meteorological data (PAR, polarimeter, temperature, humidity, etc)

- Imaging Spectroscopy

Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment

    - Hyperspectral (350nm-2500nm), 10nm channels
    - <50kg
    - 0.5 m^3
    - 200w
    - downward-looking port
    - 5-20m horizontal
    - 5-50km swath

- LIDAR
    - Waveform
    - Sufficient to resolve particles ranging from <.05 micron – 20 micron
    - reference solid earth specs (30kg)
    - 600w
    - downward-looking port
    - 1m horizontal; 15cm vertical
    - <3km swath

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- At least 2 platforms: one for in situ plume measurements (disposable), and the other for fire dynamics (higher altitude)
- Alternative is to drop instruments into the plume or
- Endurance: duration of fire 24-72 hours
- Range: Follow plume from source to deposition (>5000-10000km)
- Season: fire season goes May-September in North America

Communication needs such as real-time data or instrument control

- Deployment will be contingent upon human or satellite detection
- Over-the-horizon capability
- Realtime data telemetered to field

Carbon Cycle, Ecosystems, and Biogeochemistry – Active Fire, Emissions & Plume Assessment

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

Deployment cued from MODIS/VIIRS active fire detection or human detection. Flight prep would be determined by fire season and fire risk assessment. Follow dry lightning storms to search for new fires.

Alternatively, a high-altitude, long duration aircraft could loiter over and area for weeks to months, wait for fire, and task lower altitude assets

Prescribed burn would allow for more thorough assessment of pre and post fire carbon mass balance.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

Plume sampling would entail ability to withstand extreme vertical velocities coming off of fire.

Electric propulsion would prevent issues associated with engine air intake and fuel flammability

Frame and sensor materials would need to be fire proof

Summarize the key elements of the mission concept for this measurement.

(no input)

Carbon Cycle, Ecosystems, and Biogeochemistry – Flux Study

<u>Critical Science Question</u>: What is the flux of O2, CO2 and other trace gases between the surface (sea and land) and atmosphere and does it change with space and time?

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

Time series measurements of surface to atmosphere gas flux

- Co2 and O2 measurements – separate out land vs. ocean fluxes
  - < 0.1 ppm
- Vertical resolution of column Co2 (OCO validation)
  - Express as a function of atmospheric pressure gradients – resolve differences as low as 10mb
  - Higher resolution required in boundary layer versus mid-upper atmosphere
- Horizontal resolution – 100m for interferometer; 10m for flux measurements
- Minimum duration of 24 hours for diurnal cycle studies

Explicitly state how this observation and measurement supports this ESE science focus area.

- Supports carbon cycle science focus area roadmap
- Provide higher resolution data on sources and sinks of atmospheric CO2 on land and in the ocean
- Provide information to scale up flux measurements from tower networks

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Isotope ratio mass spectrometers, Gas chromotographer, Non-Dispersive IR Analyzer
  - 50-100kg
  - Accurate IMU – tbd
  - 3D windfield at 10hz or better
  - height and velocity from interferometer?
  - Mind the engine exhaust
  - Ancillary meteorological data (PAR, polarimeter, temperature, humidity, etc)

- Upward looking Michelson interferometer ("inverse TES") - 4 micron band
    - 50kg
    - upward viewing port
    - low altitude as possible

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Resolving horizontal distribution and errors introduced by advection through multiple platforms (depending on complexity of mission)
- At least 24 hour capability for diurnal patterns
- Seasonal measurements
- global (land and sea)

Communication needs such as real-time data or instrument control

- Pressurized, temperature controlled hard-drive for on-board data storage
- Telemetry – over the horizon capabilities for control and data relay
    - Data rate - > 1Mbs

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Observe satellite data sets (MODIS, OCO etc), file flight plan
- Flight path varies according to changes in weather, input from in situ sensors, other uavs in swarm etc.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Low as possible to 100m; appropriate to regime being measured (interferometer)
- Integration time of instruments is one determinant of speed.
- Speed of airmass being measured determines airspeed
- Racetrack pattern to follow airmass
- Multiple altitudes -- Ascending spiral for vertical measurements vs. stacked arrays of measurements

Identify any special or unique platform or mission issues

- Land fluxes are 10-50x greater than ocean fluxes.

Carbon Cycle, Ecosystems, and Biogeochemistry – Vegetation Structure, Composition & Canopy Chemistry

Critical Observation: Vegetation structure, composition, and canopy chemistry

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Improved characterization of terrestrial biomass using hyperspectral imagery, LIDAR, Radar, Interferometric radar (p, x, band – veg)
- Leaf level chemistry (eg. lignin, xanthophylls, etc.)
- Canopy water content

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Provides vegetation 3d structure, information on composition, and chemistry
- Elucidates functional groups and physiological impacts on carbon cycle

Explicitly state the advantage of using a suborbital platform for this measurement.

- Currently, these measurements are not available from space platforms, but are critical parameters for understanding the terrestrial carbon cycle.

Identify other cross-cutting areas impacted by this observation.

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, power, environmental considerations, and access such as sampling or viewing ports)

- Radar
    - Interferometric (p=ground return, x=top of canopy, L=structure)
    - <300kg (includes antennae, INU, data system)
    - <1m^3
    - 2-3 Kw
    - antennae mounts
    - 5-10m horizontal; 1m vertical
    - 5-20km swath

- Imaging Spectroscopy

  - Hyperspectral (350nm-2500nm), 10nm channels
  - <50kg
  - 0.5 m^3
  - 200w
  - downward-looking port
  - 5-20m horizontal
  - 5-50km swath

- LIDAR
  - 2 frequency (525m, 1050nm), waveform digitized
  - reference solid earth specs (30kg)
  - 600w
  - downward-looking port
  - 1m horizontal; 15cm vertical
  - <3km

- VHF Antennae
  - Need work

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location – major ecological biomes distributed worldwide
- Altitude - 40,000ft
- Endurance – 12-24hrs
- Season – all seasons
- Weekly during green-up; during freeze and thaw; associated with disturbance
- Formation flying composed up 3-7 platforms
  - All carries P/L band radars
  - Subset carries hyperspectral and LIDAR
- Straight and level flight
- Sufficient geolocation and attitude through GPS or metrology

Communication needs such as real-time data or instrument control

- 1Mb/sec for telemetry and command and control
- Over-the-horizon capability

Carbon Cycle, Ecosystems, and Biogeochemistry – Vegetation Structure, Composition & Canopy Chemistry

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Ecological transects along ecological gradients
- Observations at flux tower locations and long term ecological experiments
- Optimize collection opportunities using meteorological data

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

Identify any special or unique platform or mission issues

- Proteus as a candidate as a transitional vehicle from manned to unmanned measurements, allowing instrument integration, remote operability, and testing

- Precise position and attitude information
  - sub-meter positioning for gps (30cm)
  - 5-10 arc sec attitude knowledge
  - active metrology for radar implementation

Summarize the key elements of the mission concept for this measurement.

(no input)

Carbon Cycle, Ecosystems, and Biogeochemistry

Key Messages

- We need high-quality hyperspectral thermal suborbital sensors
- Quality of sensor is tantamount – including stability over time
- We need low-and-slow as well as high-and-slow platforms
- Radar / 3D mapping capabilities (LIDAR)
- Fluorescence imaging
- Diurnal cycle observations
- Improved data mining / data fusion
- ID and long-term observations of source / sink instabilities
- Sea-land, sea-air, land-air – remote flux measurements
- Flask sampling from UAV's
    - Consituent sampling for all important biological gases
    - Continuous stream
- High precision GPS and pointing
- All different classes of platforms
- Contemporaneous phasing of instruments and platforms and science (co-evolution)
- Improved data user interface and rapid delivery (near real-time)
- Contemporaneous measurements of passive and active are important
- Better qualification of biomass combustion
- There are many timescales that are important in addition to diurnal – seasonal, annual and interannual

Climate Variability and Change

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- Note: Bob Calahan (Lead)

Climate Variability and Change

Critical Science Questions

<u>Existing Roadmaps</u>: ***Given what we have heard about UAV and other Subortial Platforms potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?***

Climate quality observations that satisfy the 20 principles of the App 12.4 of the CCSP plan, especially including precise sustained baseline measurements in specific key regions considered representative indicators of climate change, or key source regions.

- Ice mass and thickness
- Atmospheric Radiative fluxes
- Temperature Profiles, especially in remote locations
- Atmospheric distributions of CO_2, O_3, other greenhouses gases
- Aerosol distribution, type, optical properties
- In situ measurements of cloud microphysics and chemistry
- Ocean topography at finer scales

  - Variability and climate change in Polar regions, Remote Oceans, other remote regions.
  - Need not only high-altitude, but also boundary layer platforms.
  - High-resolution measurements of key boundary conditions.

  Roles of Suborbital:
  Increase space/time resolution over space-based
  Gap – filling
  Validation
  Testbed for new ideas and instruments

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- NONE

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

What can ONLY UAVs do?

- **High spatial resolution** surveys of individual glacial basins – ground-pentrating radar, gravitometers, magnetometers, laser/radar altimeters
- **Difficult-to-access regions** to supplement ground stations: e.g. Antarctic, Arctic, remote oceans, rainforests, coral reefs, high mountains
- **Diurnal and seasonal variability, long-term changes**

Climate Variability and Change – Aerosol, Cloud & Precipitation

Critical Observation: Distributions and types of aerosol, cloud, and precipitation

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Space/time distribution of coarse and fine aerosols in regions polluted by megacity emissions and industrialized areas.
- Upstream and downstream of major source areas.
- Follow the chemical evolution and aerosol formation and removal processes in air as it moves downstream of pollution sources.
- Develop a statistical database of pollution impacts downstream of sources like megacities for a particular season.
- Follow into remote locations and possibly intercontinental transport.
- Indirect effects on cloud structure, radiation, and optical properties. Impacts on precipitation.
- Associated chemistry - ozone, sulfates,
- Perform measurements over multiyear timescale to detect longterm changes.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Improve the evaluation of climate sensitivity to forcing of aerosols by:
  - Quantifying how urban aerosol sources contribute to global aerosol budgets and loading.
  - Detecting the indirect effect of anthropogenic aerosol on cloud formation and radiative forcing.
  - Detecting multiyear to decadal trends in direct and indirect aerosol forcing.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Requires in situ sampling of clouds and aerosols.
- Requires coordinated, multilevel radiative flux measurements
- Provides capability to observe small amounts of aerosol over bright regions that satellites typically can't observe.
- Requires following plume or other pollution events over long distances.

Identify other cross-cutting areas impacted by this observation.

- Water cycle variability.
- Impacts on regional weather.
- Cloud and precipitation impacts.
- Carbon cycle through absorbing aerosols.
- Capability for detecting bioaerosol sources and dispersion.
- Education outreach for climate change and a sustainable environment.

Climate Variability and Change – Aerosol, Cloud & Precipitation

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Scanning polarimeter
- Atmospheric gas & particle samplers
  - Mass spectrometer for particle composition
  - Cloud microphysics probes
- Broadband and spectral flux radiometers
  - with precise instrument attitude measurements (<0.1° from horizontal)
- Interferometer for water vapor and other constituents
- Lidar and cloud radar
- Simple and total-sky imagers
- GPS

- Approximate payload specifications (total weight: 500 kg; total power: 5 - 10 kW; total volume: 2-3 m3; some external sampling probes and up and down looking ports

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Flights in highly populated areas downstream to open ocean (airspace accessibility); remote locations in tropical and temperate latitudes.
- Altitude: 2 - 60 Kft for cloud sampling.
- Season:
  - late summer and winter for temperate latitude locations
  - dry and monsoon for tropical latitude locations
- Range, Endurance, Availability:
  - Reach 200 km upstream to sample urban air mass origins and 2000 km downstream of targeted urban centers.
  - Map vertical and cross-track at locations 10, 50, 250, and 1250 km downstream of urban center.
  - **Sample locations daily (minimum 3 weeks) and simultaneously with multiple aircraft to reconstruct evolution of polluted air for a variety of meteorological conditions.**
  - Sample over a whole or fractional diurnal cycle at each location.
  - Expected endurance of each flight of 20 - 30 hrs at 200 ms-1.

Communication needs such as real-time data or instrument control

- Flight pattern uploadable from station
- Data rate: low bandwidth data for Q/A and instrument control

Climate Variability and Change – Aerosol, Cloud & Precipitation

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

- Simultaneous measurements along pollution transport direction might require multiple aircraft and multiple deployment locations. Aircraft may land downrange instead of returning to base.

Provide a narrative describing a "day-in-the-life" of the mission.

- L-4 : instrument payload check, weather review, go/no-go decision
- L : launch
- L+3, 9, 12, … : Review conditions, reprogram as necessary
- R : recovery
- R+4: preliminary review of data, assess quality,
- R+6: relaunch
- R+3 weeks: archive data

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Measurement locations include megacities around the world (e.g. Johannesburg, Mexico City, Singapore, northeast US, Bombay, Beijing or Shanghai, northwest Australia, Moscow).

- Raster pattern in altitude legs (2 km separation) across the track (equal to downstream distance up to 200 km) of pollution transport.

- Adjust altitude legs to sample cloud systems on some flights.

Identify any special or unique platform or mission issues

- Satellite or ground communications in remote areas
- Airspace access and air traffic control cooperation
- Requirement for large number of flight hours: quick turnaround for instruments
- Need for multiple platforms
- Multiple deployment locations and communication and coordination between sites

Climate Variability and Change – Aerosol, Cloud & Precipitation

Summarize the key elements of the mission concept for this measurement.

- **10000 flight hours typically needed per year along with low cost per flight hour (<< $1K/hr).** The success of this mission concept will depend critically on low flight hour cost because of the requirement to acquire statistical confidence and detect trends in the measurements. *In general, the statistical nature of climate studies requires low flight hour costs.*

- Facilities suitable for multiple aircraft basing
- Operation in controlled heavily used airspace over populated areas
- Dynamic adjustment of flight track and altitudes
- Wide altitude range to meet scientific objectives
- Operate in moderate weather conditions, including icing, and convection
- Rapid turn around for aircraft systems and instrument payload
- Expeditious data processing and review designed for large data rates and large datasets.
- Real-time access to instrument datasets by local population for educational outreach purposes
- Development of reliable autonomous instrumentation and availability of flight spares at deployment locations
- Quality of instrument calibration suitably high for studies of climate change and trends in climate change parameters (e.g., on board, between flight, between instruments, monitoring of instrument on board environment)

Climate Variability and Change – Glacier & Ice Sheet Dynamics

<u>Critical Observation</u>: Glacier and ice sheet dynamics: Structure, breakup, and final states

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Baseline Arctic and Antarctic, especially West Antarctic Ice distribution, and abrupt climate changes in Arctic and Antarctic. E.g.: Evolution of Larsen C, before, during and after breakup.
- Time dependence of ice and land topography, again before, during and following the breakup.
- Coastal and open ocean salinity temperature, and currents, at surface and beneath iceberg depths.
- Time evolution of targeted iceberg freeboard volume.
- Time evolution of land glacier profiles, and glacier channel profiles.
- Atmospheric boundary layer observations at high space/time resolution.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Direct observation of dynamic changes in Earth's ice cover. Will enable simulation of ice sheet dynamics and ocean interaction.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Resolution, time on station, adaptability to key climate event, ability to deploy drop-buoys in remote regions, unique ice volume and depth observations, detailed evolution of selected icebergs.

Identify other cross-cutting areas impacted by this observation.

- Water cycle variability.
- Impacts on ocean currents.
- Impacts on regional weather.
- Cloud and precipitation impacts.
- Potential to study impacts on ocean ecosystems (penguins, etc.)
- Antarctic boundary layer observations.

Climate Variability and Change – Glacier & Ice Sheet Dynamics

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Radar depth sounder
- Scanning Lidar
- Drop Buoys, drop sondes
- Microwave sounder
- RF tag system to track icebergs
- Magnetometer, gravity meter
- Atmos gas & particle samplers
- Simple imagers
- Differential GPS

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- High latitude locations, altitude 2-12 Kft
- Season: all
- Range, Endurance, Availability: Reach any part of Antarctic continent from chosen base (e.g. Punta Arenas Chile, with human infrastructure needs), TOS (minimum of X hours - requirement needs to be estimated!) and return
- Reliability, Availability: at least 50% time in the air
- Frequency: complete survey each season, before and after breakup
  Every 3 days over 2 months, during breakup
- Power: minimum 10 kW (heating needed)

Communication needs such as real-time data or instrument control

- Flight pattern uploadable from station
- Data rate: low bw data for Q/A
- Payload: 1000lb

Climate Variability and Change – Glacier & Ice Sheet Dynamics

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

- Provide a narrative describing a "day-in-the-life" of the mission.

L-12 : instrument payload check, weather review, go/no-go decision
L : launch
L+6, 12, 18, … : Review conditions, reprogram as necessary
R : recovery
R+6 : preliminary review of data, assess quality
R+7days : archive data

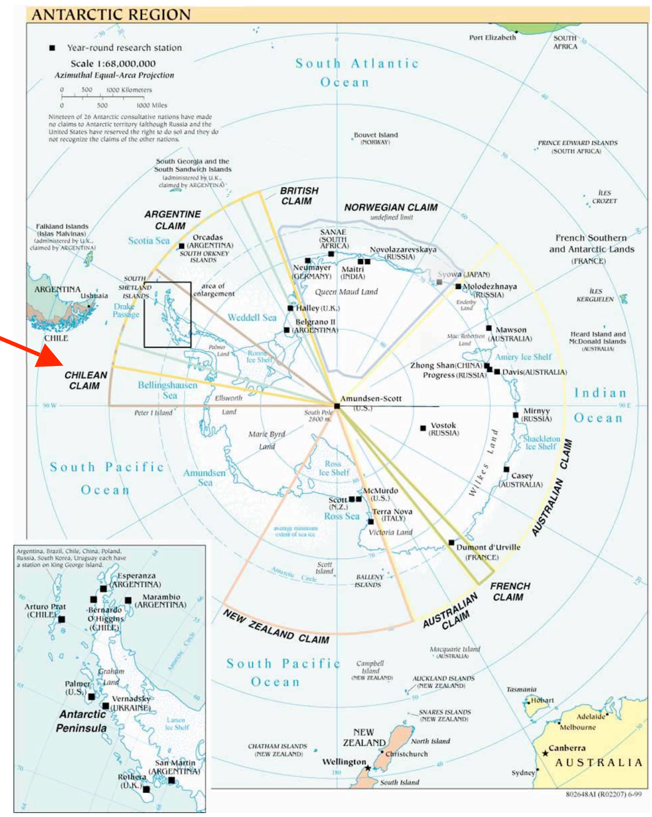
Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Ushbata (Chile)

(Larsen C:
1500-2000km ingress,
24 hours on station,
1500-2000km egress)

Predator, 110m/s, 10 hr
ingress/egress, 5000 km (14hrs)
at station (e.g. 100 km x 240
km grid on 5km spacing)

Global Hawk, 180m/s, 6 hr
ingress/egress, 15000 km at



Identify any special or unique platform or mission issues

- Rapid response climate observing system
    - Satellite or ground communications at high latitudes in unpopulated areas
    - Extremely low temperatures (< 200K). Issue for instrument and aircraft performance (fuel gelling)
    - Requirement for large number of flight hours: quick turnaround for instruments and platform or multiple platforms
    - Quick response of platform and instruments to deployment location to address dynamic ice events

Climate Variability and Change – Glacier & Ice Sheet Dynamics

Summarize the key elements of the mission concept for this measurement.

- **1000 flight hours total - low cost per flight hour (< $1K/hr)**
- Facilities: fuel depot, minimize personnel on station
- Remote cold polar regions - harsh environment
- Efficient transit
- Low altitude for science
- rapid turn around
- Expeditious data processing and review
- Precise navigation
- Reliable autonomous instrumentation and flight spares

Climate Variability and Change – Radiation

Critical Observation: Vertical profiles of shortwave atmospheric heating rates

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Measure vertical profiles of shortwave atmospheric heating rates in polluted and unpolluted clear and cloudy skies.
- Measure in regions impacted by major pollution sources such as megacities and industrial regions in different climatological regimes.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Improve the evaluation of climate sensitivity to forcing of aerosols by:
  - Quantifying how urban aerosol sources contribute to global aerosol forcing.
  - Detecting the indirect effect of anthropogenic and natural aerosol on cloud radiative forcing.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Requires in situ sampling of cloud and aerosol physical and optical properties.
- Requires coordinated, multilevel radiative flux measurements.
- Sample a variety of natural and anthropogenic aerosol types from distributed source regions.

Identify other cross-cutting areas impacted by this observation.

- Weather forecast and impacts on regional weather.
- The role of heating rates in cloud and precipitation processes.
- Carbon cycle through absorbing aerosols.
- Capability for detecting bioaerosol sources and dispersion.

Climate Variability and Change – Radiation

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

Major platform payload
- Broadband and spectral flux radiometers
  - upward and downward looking optical ports
  - with precise instrument attitude measurements (<0.1° from horizontal)
- Dropsondes or balloon-sondes for water and temperature profiles
- Atmospheric gas & particle samplers:
  - Ozone and water vapor profiles
  - Aerosol composition and internal and external mixing state
  - Aerosol absorption and scattering properties
  - Cloud microphysics probes
- Lidar and cloud radar
- Simple and total-sky imagers
- GPS

Approximate payload specifications (total weight: 300 kg; total power: 3 - 5 kW; total volume: 1-2 m3; some external sampling probes and up and down looking ports)

Small platforms:
- Broadband and spectral flux radiometers
  - upward and downward looking optical ports
  - with precise instrument attitude measurements (<0.1° from horizontal)
  - temperature monitoring in lieu of temperature control
- Simple imager
- GPS
- Transmit data from platform in lieu of data logging.
- Attitude control to 1° and knowledge to 0.1°.

Approximate payload specifications (total weight: 10 - 20 kg (< 1kg with data transmission option); total power: 10W; total volume: 100 cm3)

Climate Variability and Change – Radiation

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Flights in air parcels with diverse aerosol types in tropical and temperate latitudes.

- Altitude: 2 - 60 Kft for access to tropopause and below cloud sampling. Major platform operation between surface and 20 km (minimum 14 km). Up to ten (minimum 2) of the smaller platforms located at specified adjustable altitudes (fixed during a given mission) between surface and 20 km (minimum 14 km).
- Season:
  - late summer and winter for temperate latitude locations
  - dry and monsoon for tropical latitude locations
- Range, Endurance, Availability: Reach 100 km upstream and 100 km downstream of fixed geographical sampling point. Vertical profiles in regions with variable aerosol types and meteorological conditions. Obtain climatological variability by sampling at up to 50 different samples in a given geographical region. A sample is defined as a 6-hr on-station flight around solar noon.

- Coordinated flights of multiple small aircraft within a vertical column (100m radius tolerance) for flux divergence measurements.

Communication needs such as real-time data or instrument control

- Location and flight altitudes uploadable from station to major platforms.
- Communication from major to minor platforms.
- Data download link from minor platforms to the major platform
- Data rate from major platform if UAV: low bandwidth data for Q/A and control

Climate Variability and Change – Radiation

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

- A single major platform for atmospheric cloud and aerosol state parameter measurements.
- A fleet of smaller platforms (e.g., Aerosonde class) to make radiative flux measurement.
- Fly smaller platforms stacked in tight racetrack hovering at assigned altitudes at fixed geographical point. Instrument requirement to point both upright (nadir) and inverted (zenith) alternatively for short periods of time for flux divergence measurement from a single radiometer.
- Fly major platform in upward and downward spirals at same fixed geographical point.

Provide a narrative describing a "day-in-the-life" of the mission.

- L-3: Instrument payload check, weather review, go/no-go decision
- L: Launch major plarform and stage launch of minor platforms (mothership launch as alternative option)
- L+6: Begin recovery operation.
- R : Recovery
- R+2: Preliminary review of data, assess quality
- R+1 day: Archive data

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Choose a geographical point as a column center.
- Small platforms (Up to 10) at fixed altitudes within the column.
- Major platform spirals up and down around the column.

Identify any special or unique platform or mission issues

- Repeat flight operation of major and minor platforms on a daily or near daily basis under a variety of weather conditions at the sampling point.
- Satellite or ground communications for over the horizon communication
- Requirement for large number of total flight hours: quick turnaround for instruments and platform or multiple platforms

Climate Variability and Change – Radiation

Summarize the key elements of the mission concept for this measurement.

- **500 flight hours typically needed per study region along with low cost per flight hour (< $1K/hr for combined major and minor platforms)**
- Approximately 10 regions will be studied.
- The success of this mission concept will depend critically on low flight hour cost because of the requirement to study a large representative variety of aerosol types and meteorological conditions to acquire statistical confidence in the understanding of the process study.

- Facilities suitable for multiple aircraft basing, potentially mobile
- Dynamic adjustment of flight location and altitudes
- Wide altitude range to meet scientific objectives
- Operate in moderate weather conditions, including icing and convection for the major platform
- Rapid turn around for aircraft systems and instrument payload
- Expeditious data review
- Real-time access to instrument datasets by local population for educational outreach purposes
- Development of reliable autonomous instrumentation for the major platform and availability of spares of the minor platforms at deployment locations
- Development of reliable communications between the major and minor platforms
- Quality of instrument calibration suitably high for studies of climate change processes (e.g., between flight, between instruments, monitoring of instrument in on board environment)

Climate Variability and Change

Key Messages

Climate data grows in value with time, and requires data of sufficient quality to determine small trends that increase in importance with time. This implies the need to implement the 20 Climate Observing Principles of App 12.4 of the CCSP Strategic Plan. There is little precedent for obtaining climate quality data over extended periods from suborbital platforms. To achieve this quality routinely with aircraft will require new approaches in regard to aircraft performance, planning and execution of missions, and payload instrument performance. Aircraft will be required to stay aloft for extended periods with minimal maintenance time on the ground, have range and duration to cover a large fraction of the globe, and have facility for remote control of flight plan and flight track. Instrument requirements include greater precision and calibration stability, and reduced cost to facilitate the availability of multiple units in field deployments. Future ready availability of multiple reliable UAVs will allow meeting of unique climate needs.

Climate observing needs:

1. Need for many 1000's of hours of annual flight time over many years, for thorough sampling of climate variability and climate change. Implies different experimental regimes -- long duration, 3-d sampling, large volumes, many repetitions over climate time scales. E.g., month-long campaigns in each of several years. Also implies low cost per flight hour, fewer required personnel, reliability and maintainability. Need environmentally friendly and system friendly platforms (engine, vehicle, airspace, etc).

2. Development of instruments for difficult-to-observe parameters (e.g. polar ice thickness, subsurface ocean temperatures and salinity, precipitation). The development needs to consider potential applications on and integration with suborbital platform systems (pointability, formation flying, etc.), and the orbital, suborbital, ground-based, and subsurface system-of-systems.

3. Adaptable and readily deployable systems for climate quality observation of abrupt climate changes.

4. Onboard calibration and monitoring, thorough instrument characterization, high engineering quality systems.

5. Coordination with overflying satellites for validation of retrieval algorithms;

6. Large, reliable, longterm, easily accessible archival system.

Earth Surface and Interior Structure

Attendees

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- Note: John LaBrecque (Lead) and Carol Raymond (Lead)

Earth Surface and Interior Structure

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

The listed measurement goals are cross-cutting to the six high-priority science themes within the Solid Earth Program

- Surface deformation
- High-resolution topography
- Variability of Earth's magnetic field
- Variability of Earth's gravity field
- Imaging Spectroscopy of Earth's changing surface
- Geodetic reference frame

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Sampling of the spatial wavelengths between those sampled by surface and spaceborne vantage points, to better understand crust-mantle interactions (spatial resolution ~ observation altitude)

- Sampling of highly time-variable phenomena inaccessible from space (surface deformation, gravity changes), such as magma dynamics, transient slip on fault (aseismic slip, post-seismic relaxation). Each improvement in measurement of transient tectonic processes yields new information about the temporal complexity of these processes

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

- Comprehensive geophysical hazard observatory
    - surface deformation – topography and surface change
    - high–precision gravity
    - vector magnetometry
    - passive and active EM
    - imaging spectroscopy, including thermal IR

- Ice Sheet thickness

- Geodetic reference frame improvement

Earth Surface and Interior Structure – Surface Deformation

Critical Observation: Surface Deformation

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- The geophysical processes associated with natural hazards such as earthquakes, landslide, and volcanoes occur over a wide range of temporal and spatial scales, and express themselves as deformations in the Earth's crust. The desired accuracy in surface deformation measurement may range from a millimeter to a decimeter.
- Present observational capabilities include sampling quickly varying surface change using *in situ* GPS methods, or observing fine spatial scale changes using interferometric synthetic aperture radar (InSAR).
- Generate fine resolution, accurate observations of crustal deformation resulting from natural hazards at hourly intervals.
    - Driven by slow plate motions, rapid injection of magma into the plumbing system of a volcano can lead to explosive eruptions over hours to days. Measurements from this system will lead to better models of the internal plumbing and magma flow within a volcano.
    - Steady slip along a fault in the crust can lead to sudden, major earthquakes and days of continuing slip. Using measurements from this system a better understanding and assessment of the rate of slip and rebound surrounding a seismic event can be obtained.
    - Gradual movement of hillsides as a result of heavy rainfalls may eventually lead to catastrophic landslides. Accurate measurements of surface deformation over areas prone to landslide will assist in assessment of the process.
- Additional science studies include rapidly moving glaciers and volumetric decorrelation studies in ice and vegetation.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- From ESE Solid Earth Roadmap “Provide Crustal structure, high temporal resolution, regional deformation processes for increased predictability of earthquake and volcanic activity”

Earth Surface and Interior Structure – Surface Deformation

Explicitly state the advantage of using a suborbital platform for this measurement.

- Airborne InSAR can contribute to local measurements of rapidly evolving surfaces with temporal and spatial scales not supported by existing or planned spaceborne assets, which are not likely to exist for at least a decade or more.
- The temporal and spatial scales provided by the suborbital system would require an advanced spaceborne system such as a constellation of LEO or MEO spacecraft, or three GEO SARs.
- The suborbital platform provides this capability but for limited geographic areas.

Identify other cross-cutting areas impacted by this observation.

- Can monitor subsurface aquifer discharge/recharge
- Biomass and vegetation structure

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Use repeat pass radar interferometry with electronically scanned antenna,or single-pass InSAR using two UAVs (formation flying).
- Want very stable flight lines while staying within a desired flight tube of 10 m.
- Operate in a variety of weather conditions
- Operate from conventional airports
- Operate above 12,000 meters to avoid commercial traffic and reduce turbulence
- Able to maintain a flight path with positional accuracy of ±5 meters
- Minimum range of 2000 nautical miles (We should specify min time duration as well)
- Minimum payload capacity of 300 kilograms
- Minimum payload volume of 1 cubic meter
- Minimum 2,000 watts of DC power available for the payload (is this enough?)
- Support over-the-horizon up/downlink
- Able to mount an external, side-looking, active array antenna (0.5m by 2.0m) without obstruction

Earth Surface and Interior Structure – Surface Deformation

Mass Estimate

Radar Subsystem	**Baseline Configuration** (do you mean repeat-pass?)	**Interferometer Option** (specify baseline and UAV platform the can support this)	**Dual Frequency Option** (Specify frequencies)
Antenna	39.1	78.2	156.4
RF Electronics	8.2	11.8	20.9
Digital Subsystem	24.5	27.3	50
PDU, INU, etc…	100.7	100.7	100.7
Racks and Misc.	40.9	45.4	63.6
Radar Total	213.4	263.4	391.6

Power Estimates

Radar Subsystem	**Baseline Configuration**	**Interferometer Option**	**Dual Frequency Option**
Antenna	240	480	960
RF Electronics	194.4	216.8	411.6
Digital Subsystem	516	566	1014
PDU, INU, etc…	304	304	304
Radar Total	1254.4	1566.8	2689.6

Earth Surface and Interior Structure – Surface Deformation

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Flight lines: Straight and level lines at 13.7Km nominal altitude
- Location: Worldwide
- Seasons: All
- Persistent Observations: days to weeks

Communication needs such as real-time data or instrument control

- Low data rate over the horizon uplink/downlink capability. Broadband downlink is desirable.

Earth Surface and Interior Structure – Surface Deformation

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Fly long-level flight lines at 13,700 m in a grid pattern 50-100 km on a side (~ 3 lines in each direction over the target of interest (earthquake fault, volcano, vulnerable slopes). Data is collected and stored in a continuous mode. Refly the survey at delta-time of hours to days to weeks.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

- Single Pass Interferometry for Topography
- A baseline metrology system is needed to measure the 3 dimensional location of the antenna phase center with an accuracy of a fraction of a millimeter. This is done with a combination of INU data and a camera and ranger to each antenna.
  - INU provides accurate attitude information
  - Camera and ranger data provide accurate state vectors between a fixed point on the fuselage and a point on the antenna structure
  - Combination allows determination of the interferometric baseline

Summarize the key elements of the mission concept for this measurement.

1. High altitude UAV able to fly a stable flight line along a desired flight path within 10 m diameter tube.
2. Electronically scanned antennas to fix the antenna beam in a desired direction. This will allow for compensating for yaw angle differences between flight lines.
3. Light weight and autonomously operating radar instrument.

Earth Surface and Interior Structure – Ice Sheets

Critical Observation: Ice Sheet Thickness and Surface Deformation

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- The accurate measurement ice sheet thickness is important for the study of glaciers and global warming.
- Present observational capabilities include *in situ* low frequency radar sounding and , airborne observation using interferometric synthetic aperture radar (InSAR).
- Generate fine resolution, accurate observations of ice thickness and crustal deformation of underlying surfaces due to ice sheet loading and earth internal activities such as earthquakes.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- This measurement can provide high spatial and temporal resolution of ice sheet thickness and the underlying surface deformation.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Low altitude ad hoc network of sparse UAVs, each carrying a synchronized VHF or UHF TR module, can generate a very high resolution 3-D map of the ice sheet structure under its footprint and along its flight path.

Identify other cross-cutting areas impacted by this observation.

- Same idea can be implemented to measure tree structures and under canopy ground deformation.

Earth Surface and Interior Structure – Ice Sheets

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

1) Use many (> 50) microaerial vehicles in an ad hoc formation flying (footprint ~ 100 diameter)
2) Require relative position of UAVs with respect to a coordinate system to within a fraction of a wavelength. (need differential GPS)
3) Need a communication link (to satellites, nearby base-stations, or a larger UAV flying over the MAVs)
4) Operate from conventional airports
5) Operate at an altitude of about 200 meters or less to achieve high resolution and for S/N consideration.
6) Minimum range of 200 Km (to get a raster image of 10KmX 2Km)
7) Minimum payload capacity of 3 kilograms
8) Minimum payload volume of 10^{-3} cubic meter
9) Minimum 10 watts of DC power available for the payload
10) Support over-the-horizon up/downlink

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Flight lines: Straight and level lines at 150 m nominal altitude
- Persistent Observations: days to weeks

Communication needs such as real-time data or instrument control

- Relatively high data rate over the horizon uplink/downlink capability.

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Parallel lines to create a raster image

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates. *(no input)*

Identify any special or unique platform or mission issues *(no input)*

Summarize the key elements of the mission concept for this measurement.

- Low altitude formation flying of a large number of very small UAVs .

Earth Surface and Interior Structure – Imaging Spectroscopy

<u>Critical Observation</u>: Surface solid earth composition, change, related atmospheric phenomena

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Surface composition, change, water vapor and sulfur dioxide in space and time.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Called out in SESWG
- Measures the composition and change in the solid earth at the Surface atmosphere interface.
- Measures accurate precise 3D water vapor for GPS based derivations.
- Measures 3 D SO2 and other phenomena associated with active volcanology WITH TWO BREAD BOXES.
- Measures earthquake fault optical spectroscopy properties before and after

Explicitly state the advantage of using a suborbital platform for this measurement.

- Need rapid response.
- Need hourly sampling over the course of a day.
- Need spectra, high spatial resolution, and angular acquisitions.

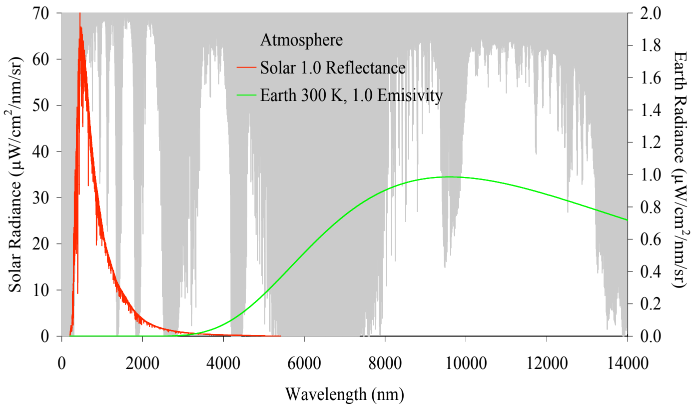
Identify other cross-cutting areas impacted by this observation.

- Carbon, Ecology, Atmosphere, etc.

Earth Surface and Interior Structure – Imaging Spectroscopy

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)



- Measure the optical spectrum from 400 to 2500 nm at <=10nm as images 36 degree swath with 1 milliradian sampling.
- Measured 7000 to 13000 nm at <=40nm as images 36 degree FOV and 2 milliradian sampling.
- Measure both with point angle range to all tomography
- Flight Characteristics over site 12 to 24 hours, over days to months, altitude 45kft
- Real-time data required

- Mass: 50kg, Power: 200W, Volume 0.5m3, down looking port.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Global response
- Altitude 45kft

Communication needs such as real-time data or instrument control

- Telemetry and quicklook

Earth Surface and Interior Structure – Imaging Spectroscopy

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a “day-in-the-life” of the mission.

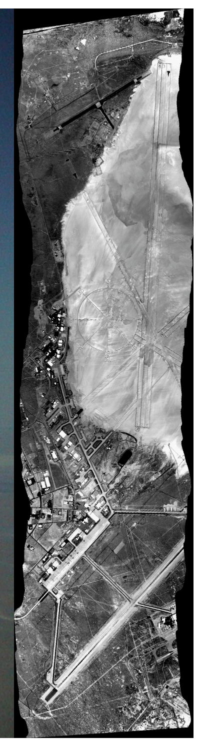
- Mode 1: Collect baseline and periodic monitoring
- Mode 2: Begin acquisition suite based on hypothesized hazard
- Mode 3: Respond after phenomena (volcanic eruption, earthquake, flood, etc)

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.
(no input)

Identify any special or unique platform or mission issues
(no input)

Summarize the key elements of the mission concept for this measurement.

- Measure spectra as images in rapid response and in monitoring mode.



Earth Surface and Interior Structure – LIDAR

<u>Critical Observation</u>: Continuously operating, targeted, high-resolution topographic mapping and topographic change-detection of the ground surface, including where covered by vegetation

- All-terrain topographic change detection by repeat mapping compliments interferometric SAR measurements of sub-cm to decimeter surface (e.g., observe decimeter to tens of meter near-field surface deformation in the vicinity of ruptured faults and inflating volcanoes to understand earthquake and magmatic processes; observe decimeter to hundreds of meters topographic change associated with landslides, volcanic eruptions and flows, coastal and fluvial erosion and sediment redistribution)

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Targeted local to regional mapping, with global access, at 1-m resolution and 0.1-m vertical accuracy (referenced to a globally defined absolute datum)
- Repeat frequency of hours to years depending on the rate of topographic change

Explicitly state how this observation and measurement supports this Earth Science focus area.

- This is the long term (10 to 25 year) goal for high-resolution topography mapping identified in Living on a Restless Planet, the report of the NASA Solid Earth Science Working Group.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Targets of highest priority are narrow, long, quasi-linear features (e.g. fault zones, coastal zones) amenable to targeted mapping or point features (e.g. volcanoes) amenable to station-keeping monitoring
- Required temporal and spatial coverage is not achievable from near-space orbital systems (LEO/MEO) with technology likely to be available in the next 10 years
- Required spatial resolution and vertical accuracy is not achievable from far-space orbital systems (L1/L2,HEO/GEO) with technology likely to be available in the next 10 years

Identify other cross-cutting areas impacted by this observation.

- High-resolution elevation mapping and change detection are equally applicable to measurements of inland water storage and discharge (from changes in water stage, slope, and extent), ice sheet mass balance, glacier and ice stream dynamics, snow pack depth, sea ice thickness, vegetation cover attributes (e.g. biomass, forest fire fuel quantity and quality), and solid planet and moon surface topography

Earth Surface and Interior Structure – LIDAR

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Geodetic imaging lidar (i.e., scanning laser altimeter) integrating time-of-flight ranging of pulsed or encoded continuous-wave laser light, precision trajectory determination, and precision attitude determination

  - Mass 30 kg (1/3 COTS)
  - Average power draw 200 W (1/5 COTS)
  - Volume 40 x 40 x 40 cm (1/2 COTS)
  - 1.5 million range observations per sec (10x COTS)
    - (3 km swath width, 5 returns per 1 m pixel, & 100 m/sec ground speed)
  - 20 km flight altitude (10x COTS)
    - (near-nadir ±4° scan to achieve swath while preserving water returns and reducing pointing-induced range errors)
  - Post-flight knowledge of the aircraft flight path:
    - <5 cm radial (= COTS) over 200 km GPS baselines (10x COTS)
  - Post-flight knowledge of sensor attitude: 5 arc sec per axis (20x COTS)

  - COTS system used for comparison is the Optech ALTM 3100 (a representative state-of-the-art commercial system)

- The above is a representative instrument configuration. Trades can be made between flight altitude, swath width, data density, off-nadir scan angle, vertical accuracy and attitude knowledge. ±4° scan angle is an upper limit to acquire returns from smooth water surfaces which act as specular reflectors. Flight altitudes above commercially controlled airspace are desirable for operational efficiency in following and later repeating specific flight lines.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Single platform operating at 20±2 km altitude and 100±20 m/sec ground speed targeting altimeter swath on pre-programmed ground track with cross-track accuracy of 150 m (achieved by combination of real-time navigation and sensor steering to compensate for platform roll). Adjacent altimeter swaths are overlapped cross-track by at least 50% to enable cross-calibration between swaths, consistency checks anywhere, and complete data coverage in case of data outages on single flight lines. Locations would emphasize tectonic plate boundaries (for fault zones and volcanoes) and coastlines, with access to international air space required for data collection. Data collection would consist of offset, parallel, overlapping flight tracks to build up a corridor of data covering the region of interest. There is no specific seasonal requirement, although for precise ground topographic mapping snow-free conditions are required and leaf-off conditions for areas of dense deciduous cover is preferred.

Communication needs such as real-time data or instrument control

- Primarily autonomous operation but periodic, over-the-horizon low rate communication for performance assessment and command/control. On-board intelligence with operational limits for instrument health and safety, as done for orbital instruments.

- Full rate data stored on board for retrieval at end of flights of hours duration. High-bandwidth data downlink for flights of days duration (Mbits/sec).

- Sensor web implementation to autonomously provide weather and cloud cover information to platform, which then optimizes flight path to acquire data in clearest areas.

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

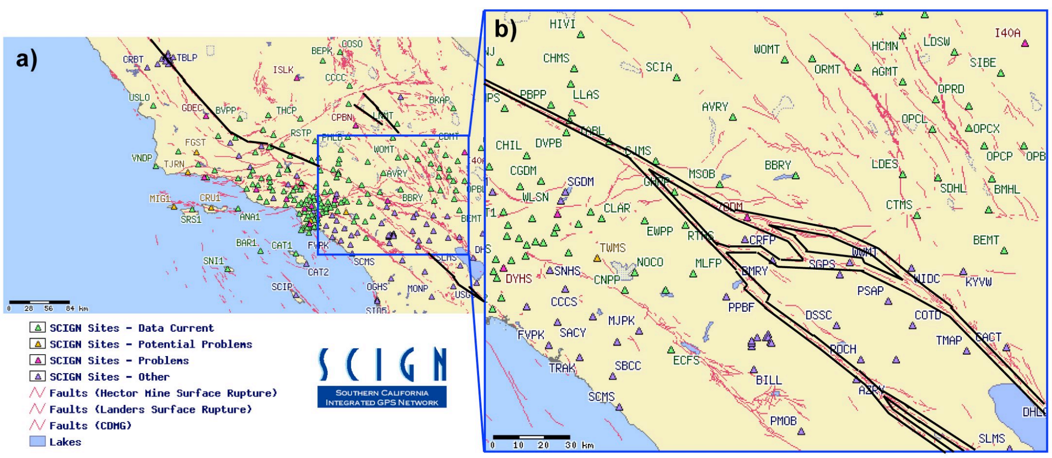
- Mission consist of two parts:
  (1) Comprehensive "baseline" mapping of areas likely to experience future surface deformation and topographic change due to natural hazard events (e.g. active fault zones and volcanoes, shorelines susceptible to storm surge flooding and erosion). This can be conducted over an extended period of time, as UAV assets are available. For specific areas of active faulting (e.g. southern California), total fault lengths of the order 1000 km would typically be mapped. The total data line length would depend on the number of overlapping swaths required to build up the necessary data corridor along the fault system. The required data corridor depends on the sinuosity and complexity of the fault zone and the expected width of surface deformation and topographic change of a magnitude large enough to be observed by this technique. Data line lengths of the order 10 times the fault zone length are likely given the assumed 3 km wide swath width and 50% sidelap.

  (2) Concentrated response mapping in areas where other observing capabilities indicate precursory surface deformation may be occurring

(e.g. volcano inflation indicating the potential for eruption) or where natural hazard events have occurred (e.g., earthquake, eruption, storm surge) to establish surface deformation and topographic change directly associated with the event (requiring deployment within hours to several days) and to observe transients following the event (continued for days to weeks). Typically fault lengths ruptured during a significant earthquake are of the order 100 km. Total data line lengths would depend on the number of overlapping swaths required to build up the necessary data corridor along the ruptured portion of the fault system.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Constant flight altitude, with corridors of data composed of overlapping flight swaths along relatively straights segments of fault zones or coastlines. An example of the comprehensive baseline mapping of corridors that might be done along selected southern California active faults (in red) is indicated in the figure by the black lines.



Identify any special or unique platform or mission issues

- As previously stated, precision knowledge of the aircraft flight path (5 cm) and sensor attitude (5 arc sec) are required post mission for processing of the data.

Summarize the key elements of the mission concept for this measurement.

- High spatial resolution (1 m), high vertical accuracy (0.1 m) observations of the ground surface, including where covered by vegetation, referenced to an absolute datum and repeated through time to observe surface deformation and topographic change achieved with a geodetic imaging lidar.

Earth Surface and Interior Structure – Gravitational Acceleration

<u>Critical Observation</u>: Gravitational Acceleration

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Gravitational acceleration is the acceleration due to mass attraction and varies spatially and temporally near Earth as a consequence of the inhomogeneity and the dynamics of Earth's mass density structure.
- Spatial variation occurs at all scales, from thousands of km, due to core/mantle boundary anomalies, to sub-kilometer and smaller, due to local topographic (or bathymetric) masses.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Earth's gravitational field defines satellite orbits, affects inertial navigation, reflects oil and mineral deposits, and characterizes crustal geologic structure. The equipotential surface, known as the geoid, defines a reference for sea surface topography (leading to oceanographic current determination through satellite ocean altimetry), and it defines the conventional reference of heights for national vertical geodetic control.
- The precise determination of the geopotential at global scales is sensitive to motion of oceanographic, hydrographic, and atmospheric masses. Its temporal variation at local and regional scales, reflecting mass motion at these scales, is potentially measurable with new-generation gravity gradiometers

Explicitly state the advantage of using a suborbital platform for this measurement.

- Moving-base gravitation measurement systems have been developed for satellites, aircraft, and ships. Satellite systems have global sensitivity and extent, but are limited in local resolution to scores of kilometers due to the ground-track speed of about 7 km/s. Moreover, the vertical attenuation of the field places severe sensor accuracy requirements on the system.
- Sub-orbital (i.e., aircraft) systems have higher resolution capability (kilometer and potentially sub-kilometer) that will not be attained by any satellite system in the foreseeable future, and they are somewhat less demanding in accuracy, but also more affected by the dynamics of the vehicle.
- Sub-orbital platforms have a large benefit-to-cost ratio, especially in remote and inaccessible regions of the world. This would even increase with less expensive vehicles (such as UAV's) that are remotely controlled and operated.

Identify other cross-cutting areas impacted by this observation.

- Sub-orbital gravimetry systems complement and supplement satellite systems, by supporting validation and extending the resolution of sensors to the kilometer range. They are more readily combined with other solid Earth measurement systems, such as topographic mapping (SAR and Lidar) and magnetometry, for a comprehensive assessment and characterization of local and regional geophysics and geodynamics. Clear benefits include improved modeling of tectonics and associated volcanism and earthquake hazard zones.

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Gravimetry systems are based on two independent acceleration measurement systems: kinematic acceleration (typically derived from precise GPS positioning) and inertial acceleration, obtained from accelerometers (or gravimeters). GPS is now a given utility on any moving-base science platform and thus does not enter the instrument/payload characterization.
- Accelerometers require precise orientation with respect to inertial or navigation coordinate frames. This can be achieved by elaborate stabilized platforms, or mathematically with accurate sensing of the angular dynamics of the vehicle.
- Either mechanization requires some type of gyroscopes. Total vector gravimetry can be achieved with navigation-grade inertial navigation systems (produced by leading military and civilian avionics industry) that contain three accelerometers and three gyros.
- Such as system is totally autonomous, weighs about 20 lbs, occupies about 7” x 7” x 12” in volume with minimal clearance needed for heat dissipation, and consumes about 20 W (?) in power. Built for military applications, they have high environmental tolerances.
- Data interfaces and data logging equipment, currently, are not optimized for volume (typically based on desktop computers or laptop computer with docking station). Time synchronization with GPS time is critical and may be achieved with a built-in GPS receiver.
- These systems have been shown to yield precision in gravitation determination of a few parts in 10^6 with resolution of about 10 km (typical 100 m/s vehicle velocity).
- Other sensor options exist with varying capabilities. Current MEMS inertial measurement units are probably only marginally able to detect the un-modeled vertical gravitational component (at parts per 10^5). However, their volume, weight, and power consumption (?) are lower by a factor of 10. Dedicated airborne gravimeters yield the vertical component at 1-2 parts per 10^6, but are larger, heavier, and consume more power by a factor of 5 (?).

- Gravimetry systems may also consist of acceleration gradiometers. In various design and development stages during the last four decades, gradiometers have only recently been put to use for geophysical survey operation, though only in a limited capacity due to their high cost ($2-3M). Their size, weight, and power consumption are comparable to airborne gravimeters (?). New technological developments (e.g., using atom interferometers) promise significant resolution enhancement and accuracy over current systems as well as accelerometer-based systems. Instrument characteristics for these are un-known at this time.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Since gravimetry data need to be processed further using potential theory for geophysical interpretation, ideal surveys would yield regular, gridded data sets at constant altitude.
- Typically parallel straight tracks are surveyed with a number of cross track needed to remove between-track biases and trends. Track spacing should be comparable to along-track resolution (e.g., 10 km).
- Proximity to the mass anomalies enhances the signal-to noise ratio, therefore, low altitude is desirable (this may be offset by increased system error due to higher turbulence at lower altitude). Typical altitudes are 5000-10000 m.
- For strapdown inertial navigation systems and gravimeter systems, long (> 100 km), straight, and level tracks are preferred to minimize deleterious effects of aircraft dynamics associated with turns and accelerations in altitude.
- Repeat tracks (or multiple sensor systems) enhance ability to remove non-gravitational systematic errors.
- For accelerometer and gravimeter-based systems, continuous GPS visibility is required.
- Precision positioning (1 Hz, for kinematic acceleration determination) normally (currently) requires ground base station support (for differential phase data processing) not more than 100 km distant from vehicle.
- Geospatial registration (by GPS) is required to an accuracy of 3 m.

Communication needs such as real-time data or instrument control

- Real-time data transmission to base station is not required, since post-mission processing of data is the common application.
- Basic instrument requires data logging and data interface equipment.

Earth Surface and Interior Structure – Gravitational Acceleration

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- INS-based systems require a period (e.g., 5-7 minutes) of attitude initialization prior to take-off (this is done automatically by a navigation-grade INS; it could be done post-mission with MEMS IMU's).
- For UAV deployment, the vehicle would follow pre-programmed trajectories as described above.
- Tolerance on trajectories is estimated to be +/- 30 m (?).
- Upon the return of the vehicle to the base station, the data are downloaded and archived for later processing of the total mission.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Sample test surveys can be illustrated.

Identify any special or unique platform or mission issues

- See Observation / Measurement System Requirements

Summarize the key elements of the mission concept for this measurement.

- Using current INS technology requires precision GPS positioning and long, straight, level tracks. Typical surveys consist of multiple parallel tracks, but other sortie geometries might be considered (e.g., radial pattern from the center or from the circumference of a circle). Cross-tracks are essential to estimate relative biases and trends.

Earth Surface and Interior Structure – IPY Platform

Critical Observation: Low-altitude Surveying for Antarctic Exploration in the IPY

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Coordinated magnetometer, gravity, lidar measurements from a small, easily deployed autonomous low-cost vehicle. Basic mapping to determine ice sheet bed characteristics, and ice sheet elevation, examine the geologic controls on ice sheet dynamics.

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Lightweight compact vector or scalar magnetometer
- Strapdown gravity system
- Small lidar system

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Flight lines from the coast into the interior and cross over. Range of minimum 500 nm, deployment from ice breaker.

Communication needs such as real-time data or instrument control

- Low-data-rate telemetry

Mission Concept: Describe in as much detail as possible the measurement approach:

(no input)

Earth Surface and Interior Structure – Magnetic Fields

<u>Critical Observation</u>: Measure vector and tensor magnetic fields to support comprehensive magnetic field source models and isolate time-varying crustal field components

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- The magnetic field spectrum is undersampled in the spatial wavelengths intermediate between the near-surface (up to 2 km) and satellite altitude (350-700 km). These measurements are critical to producing models that account for all sources of magnetic fields from crust to core.
- The simplest implementation is a calibrated vector magnetometer on a single UAV, to simultaneous measurements from coordinated platforms over a wide area to eliminate noise from external time-varying fields, to magnetic tensor measurements using four microUAVs flying in formation.
- Measurement of the tensor has the advantage of enabling direct measurement of currents within the volume of the measurement space defined by the sensor array.
- Gradient tensor measurements would further allow the separation of field sources.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- This observation addresses the need to measure variations of the Earth's magnetic field to in support of studies of the magnetic field behavior, geophysical and tectonic processes in the crust, and highly time-varying fields due to piezoelectricity (stress induced), fluid flow and magma dynamics.

Explicitly state the advantage of using a suborbital platform for this measurement.

- The altitude range, system size and weight, and desired surveying characteristics needed for these measurements is best suited to a microUAV platform.

Identify other cross-cutting areas impacted by this observation.

- Atmospheric electricity, cloud microphysics, buried/submerged object detection.
- Highly complementary to gravity and surface deformation measurements for hazard detection.

Earth Surface and Interior Structure – Magnetic Fields

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Magnetometer <2000 g (with electronics), <1000 cm3, need magnetically quiet vehicle, and few arc-sec attitude knowledge at 1 Hz. Sampling at few Hz to 20 Hz.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Single UAV flight altitude between few km up to 35 km. Long flight lines or grid surveys.
- Prefer night flying (quiet external fields environment).
- One-time survey (for combining satellite and surface data).
- Except for time-varying field monitoring, which could be done monthly to daily for high priority targets, and yearly or every several years for baseline time series.

Communication needs such as real-time data or instrument control

- Data volume is low, could be stored onboard.

Earth Surface and Interior Structure – Magnetic Fields

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Launch single or fleet of UAVs
- Fly prescribed lines or grid survey
- Land and dump data or downlink during flight

- Formation:
  - Launch group of four UAVs and maintain formation with 100's of m to kms length separation baselines (to TBD separation accuracy) for length of flight.
  - No time constraint on completing a single survey.

- Could be combined with gravity and lidar

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

- Magnetically quiet vehicle

Summarize the key elements of the mission concept for this measurement.

- Fly microUAVs alone or in formation with calibrated vector instruments (including precise attitude knowledge)

- Fly baseline surveys and measure time-varying magnetic fields with frequent repeat surveying

Earth Surface and Interior Structure

Key Messages

Issues of Importance to the Earth Surface and Interior Focus Area:

1. UAV/OPV will provide high resolution continuous 4-D observations that will not be available from spaceborne platforms for 10-15 years minimum

2. Because of natural attenuation of geopotential fields, UAV's can provide high spatial and temporal resolution observations not possible with satellites. High altitude UAV measurements provide quiescent observations needed for ultra high sensitivity measurement of the gravity field and will fill spectral gaps between geopotential satellite observations and national and commercial near surface studies.

3. Reconfigurability and adaptability of UAV's to instruments is an important enabling feature such as in radar applications where aperture design is an issue.

Across Focus Areas

1. Access to international airspace (airspace of other nations) for UAVs is a critical issue-an argument for OPV availability in the near term.

2. Need OPV as transition to UAV for the development of instrument technology, exploration capability, and algorithms.

3. Readily accessible low cost UAV fleet will provide important and valuable development platforms for rapid concept development and testing.

Water & Energy Cycles

Attendees

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- Note: Jared Entin (Lead)

Water & Energy Cycles

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- River Characteristics (static and variable) Topography, Roughness / Discharge (7,000 rivers) – Floodplain assessment

- Cloud properties and extent (ice content, radiative, profile)

- Precipitation – especially storm tracking – hurricanes, blizzards, etc.

- Snow water equivalent

- Water and temperature profiles in the atmosphere

- Soil moisture (esp. higher spatial resolution and/or deeper depths)

- Surface evaporation (Land & Ocean)

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Water quality
- Land subsidence for groundwater change
- Snowfall
- Soil characteristics (freeze/thaw condition, type)

- Ocean surface properties (salinity, temperature, wind)

- Boundary layer dynamics

- Drought (what is it? Vegetation health, soil deficit)

Water & Energy Cycles

Critical Science Questions

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

- *Overarching Concern: Global Measurement Capability (internationally)*

- River Characteristics
  - Smart flying (sensor control direction?)
  - Multiple sensors
  - Global Measurement capability (international)

- Cloud properties
  - Tandem flying (vertically and horizontally)
  - Cloud fly through ability
  - Altitude concerns (for above/in cirrus clouds)
  - Multiple sensors, complex sensors?

- Soil Moisture
  - Large antenna required (for P-band or spatial resolution)

- Snow Water Equivalent
  - High spatial resolution
  - Difficult flying (topography issues, poor conditions)

- Storm tracking
  - Bad weather flying

- Vegetation Characteristics (Type & health)
- Boundary Layer assessment
  - Small UAV piloting (safety)
  - Formation flying (3-D assessment)
  - Multiple sensor & sensor accuracy

- Water Quality

Water & Energy Cycles – Cloud Properties

<u>Critical Observation</u>: Cloud Properties

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- In situ micro-physics of all clouds.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Better understanding of cloud dynamics should lead to improve representation in weather and climate models. This could result in improved precipitation forecasting as well as radiation balances.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Can't get in situ of clouds any other way!

Identify other cross-cutting areas impacted by this observation.

- GPM, Cloudsat & Calipso cal/val instrument.
- Useful for Weather, Climate focus areas as well.
- Synergies with Atmospheric Composition FA and ARM program

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

1. Passive microwave Imager (from high altitude for ocean & land coverage and movement capability to follow systems). Ideally 10 – 600 Ghz range. Minimally 19-183 Ghz range.
2. Dual-pole Multiple Frequency microwave radar (13, 35, 94 Ghz. ?)
3. in-situ sensors – cloud particle imagers, perhaps others?
4. Lidar
5. Smart drop sonde

Water & Energy Cycles – Cloud Properties

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Minimum of two aircraft (one high imager, one in situ). Multi in-situ would be preferred b/c of fine spatial & temporal scale dynamics.

- Altitude: Imager needs high altitude capability (lower stratosphere, 25km?), lower bound would be order 1 km. In situ fliers would require similar altitude range and go all the way down to the surface.

- Formation flying: in situ flight path controlled by data retrieved from high flier. Updrafts in clouds could provide some lift and enhanced endurance.

- Endurance: For Imager at least 24-48 hours though longer (~1 week) would provide much greater science return. In situ system to provide coverage for 24-48 hours (perhaps by using multiple successive fliers).

- In situ samplers would benefit to having some vertical control, including multiple ascent/decent capability, spirals through the clouds and boundary layer.

- Range: Having 10,000km transport range for imager (prior to hovering) would be helpful. Range for in situ fliers on order of 10 kms.

- Positional information required to accuracy of 10 meters for all systems. Good attitude position accuracy (0.1 degree) for imaging aircraft.

- All season, including hurricanes and blizzards.
- Tropics and mid-latitudes (both over land and ocean).

- One option would be to have a high altitude storage ship that contains many of the smaller in situ sampling UAVs. The Imager communicates to the storage ship location and distribution of small samplers. Storage ship would require similar range & altitude as imager. Endurance could be less (24-48 hr range). This frees up the in situ samplers to be minimal in propulsion.

Communication needs such as real-time data or instrument control

- Imager needs to be able to communicate flight instructions to in situ platforms. Data download from in situ platforms needs to occur in flight (near real time) in case in situ fliers are lost during flight. In situ platforms might require smart systems to turn on/off and direct their instruments while in flight, based on its own observations or imager direction.

Water & Energy Cycles – Cloud Properties

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Aircraft & instruments are shipped to base of operations. Could require fast (1-3 days) action from off shelf to shipping, integration, and launching into action.
- Imager hovers or circles in region of interest and looks for critical environmental characteristics. It then tasks the release and direction of the in situ samplers (perhaps using a storage ship as a mechanism).
- Upon activation, in situ samplers fly in clouds, have two-way communication with Imager ship, and return observation data to Imager/Storage ship and/or directly to ground or satellite if possible. In situ samplers may safely hover down to earth surface upon completion or exhaustion (biodegradeable? Collectable for reuse?). In situ samplers might be requested to take observations on descent.
- Mission data is reviewed by a "mission control" and then Mission plus (analyzed?) observations data is reviewed by larger team for improved performance in future uses.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Mostly captured in "day in the life". Transportable to Global operations excluding polar regions. (beyond 70 degrees?). Could be used in directed field campaign mode as well as continuous automated observation.

Identify any special or unique platform or mission issues

- In situ aircraft should not influence its own measurements or the cloud evolution (via chemical or heat exhaust etc.)
- Aircraft need to be able to survive and operate in harsh cloud condition. Although with relaxed flight path control.

Summarize the key elements of the mission concept for this measurement.

- Two types of vehicles in this mission – both high altitude and durable.
- One (the Imager) with good position and attitude control for observations, the other (the in situ) able to take observations at all levels of atmosphere.
- Having multiple in situ (10-100) would strongly enhance science return, even if they were lightweight (<2 kg). Would also allow multiple type of in situ & sensor combination that are more tailored for area of deployment as well as information retrieved by the imaging ship (including returned information from "early" deployed in situ observer).

Water & Energy Cycles – River Discharge

<u>Critical Observation</u>: River Discharge

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- River discharge – the volume of water flowing in a river, at multiple points. In order to obtain this, we need two things:
  - River geometry, obtain from lidar mapping
  - River heights, obtained from altimetry.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- These observations are critical for global and regional water balance studies.

Explicitly state the advantage of using a suborbital platform for this measurement.

- High spatial accuracy. If using lidar the ability to fly underneath (some) cloud covers would be advantageous. Advantage being able to dynamically do measurements up/down rivers. Obtain geometry by hand is extremely costly (and difficult).

Identify other cross-cutting areas impacted by this observation.

- Critical information for other agencies (USGS, EPA, etc.). Also important information for oceanography and coast zone studies. Can also use the lidar measurements for floodplain mapping.
- Micro-submersible technology could complement or used as a co-driver.

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- These two would be on different platforms:

1. Geometry – Scanning Lidar – 25kg, 0.2 m^3, 500 watts.
2. Stage Height – Dual freq. radar (to help mask out vegetation induced roughness). 200kg, 1-5 kilowatts. Size depends on antenna size. Also C-band along-track radar interferometer on both platforms for additional calibration and cross platform comparison.

Water & Energy Cycles – River Discharge

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location: Global land areas.
- Altitude: 5-10 km for SAR (echo shouldn't interfere with emittance.) On clear days both can fly in the 5-10km range. Low to the ground for Lidar can be helpful but removes C-band data.
- Endurance: As long as it takes to fly the river channel, could be 1-24+ hours – depending upon desired level of resolution (primary channels, secondary channels, tertiary etc.)
- Season: Geometry is best done during low flow (can be late summer/early fall). River heights done year-round, especially during higher flow (after snowmelt).
- Frequency – The geometry needs to be done a few times a river. The river discharge could be on demand or weekly. Freq. is going to be dictated by the number of rivers and what extent of each is desired to be covered.

- Two Platforms

- Special Flight characteristics – Each might need to be able to follow the river's path. This could be done by coordinating with on board instruments.

- If flown during non-calm conditions the radar platform would require some precision flying in rough conditions.

- High precision knowledge of sensor footprint required.

Communication needs such as real-time data or instrument control

- The instrument must be tied to aircraft directional control.
- Communications with base could be limited to housekeeping data and basic data quality.

Water & Energy Cycles – River Discharge

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Option 1:
    - The Lidar platform is sent out to fly the length of the desired river channel. The lidar measures the geometric characteristics of the river and its path and uses that to control the flight track of the aircraft. Aircraft returns to base and information is extracted and analyzed.
    - At some later time the Radar platform flies the same river channel, though it might not necessarily fly the entire track, just the sections over which the river surface heights are desired.
- Option 2: (assuming each has C-band along track radar)
    - Both platforms are sent out to fly the length of the desired river channel.
    - The lidar measures the geometric characteristics of the river and its path.
    - This path information is used to control its flight track as well as the SAR platform behind it.
    - Upon return information is extracted and analyzed.
- Option 3: On demand.
    - During critical events (or during/just after heavy (upstream) rains) the SAR platform might be detailed to fly over a given river.
    - This would probably only be done after the first platform had flown over it at least once.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Flight profile is going to be determine by which section of the river is desired (if not all).

Identify any special or unique platform or mission issues

- Lidar must fly underneath clouds and close to the ground if possible and safe.
- Accurate position precision for both platforms is required.
- Stable platforms helpful for improved mapping accuracy.
- SAR platform should be high enough for robust measurements (minimum 4 km.?)

Summarize the key elements of the mission concept for this measurement.

- There is a tremendous opportunity here and the platforms can operate separate or together to acquire critical information.
- Suborbital allows the ability to obtain hard to get (if not impossible) measurements globally.
- Allow for accurate mapping of floods in inundated areas.
- The UAV platforms must be stable and precise in position knowledge to obtain the data quality required.

Water & Energy Cycles – Snow–Liquid Water Equivalent

<u>Critical Observation</u>: Snow – Liquid Water equivalent

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Measuring the water stored in the snowpack, at very high spatial resolution (~50 m). Also getting snowpack characteristics such as depth, density, wetness, age, emissivity, albedo, etc.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Getting the melt quantity and timing has significant application for decision makers. Also, knowledge of the snowpack is important for water budget studies. Would allow for improvement in prediction of snow (weather & climate) as well as understanding the climate data record provided by snow cover measurement.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Higher spatial resolution and better temporal revisit timing. Ability to resolve measurement in mountainous regions…where there happens to be a lot of snow.

Identify other cross-cutting areas impacted by this observation.

- This would be of interest to weather and climate focus areas.
- Many Federal, State, and local agencies want this type of information (for example, USGS, USDA, NOAA, Western Governors Assoc., etc.)
- Useful for NPOESS calibration

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Dual Freq. SAR (C & Ku band)
- Dual Freq. Radiometer (K & Ka band)
- Visible and Thermal camera
- This might be 300kg for both.
- Total power 1kilowatt

- Must be able useable in cold season and mountain environments.

Water & Energy Cycles – Snow–Liquid Water Equivalent

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location: Primarily, seasonally snow covered regions over the globe. Secondarily, in permanent snow covered regions and regions where snow is over ice / sea ice.

- Altitude: near surface (100m) to lower altitudes (<10 km)

- Endurance: 24 hrs. Less is allowable for complex terrain flights (see below)

- Season: (local) Fall, Winter, Spring primarily.

- Frequency: Able to maintain 70-80% duty cycle in a week, and sustain this over the snow season (this could be >6 months).

- Aircraft and footprint location precision: <10 meters

- Special Flight Characteristics: Being able to fly over complex terrain (mountains) and doing precise height over ground altitude (within a few meters precision), while keeping a relatively stable instrument attitude (3° pitch, 5° roll, 3° yaw). Sixty degree roll angle for instrument calibration (non-show stopper, other calibration possibilities considerable).

- Ability to drop sondes of some undefined characteristics would be useful. This would require the development of the appropriate small in-situ sensors.

- Multiple platforms would enable greater spatial coverage (this could be critical for doing more than just "science research" i.e. providing information for applications). Exact coverage would depend upon altitude and sensor specifics.

Communication needs such as real-time data or instrument control

- Two-way Housekeeping data for instrument health and limited flight control.

Water & Energy Cycles – Snow–Liquid Water Equivalent

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Aircraft and instrument are transported to "host" airport. Necessary calibration and validation is done on sensors suite.
- Aircraft is programmed with flight line instruction. This could be driven by event (recent snowfall, field experiment desires, or season long monitoring of selection basins).
- Aircraft flies and sensor observes, potentially drops mini in situ snow sensors. Aircraft may be doing complex flight path, either to hit particular ground targets, keep a constant altitude, or topographic avoidance maneuvers.
- Aircraft returns to airport. Data is downloaded (should be doable in less than an hour). Aircraft refreshed for new flight.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Flight profiles and maneuvers would depend upon location of observation.
- Geographic coordinates: Primarily in seasonally snow covered regions.

Identify any special or unique platform or mission issues

Ability to handle mountain terrains and (limited) winter storm conditions.
Ability to operate over populated region (safety, noise).
Maintain the attitude of the aircraft in the mountain regions.

- Summarize the key elements of the mission concept for this measurement.

A Suborbital platform that can carry and provide suitable stability for the suite of instruments (critically the active/passive microwave instruments) in the areas and times of interest (mountains, winter).

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Critical Observation</u>: Soil Moisture & Freeze/Thaw states

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Characteristics of water in soil (in presence of vegetation):
  1. Surface soil moisture (0-5cm, i.e. L-band)
  2. Deep soil moisture (5cm – 5m, i.e. P-band or longer wavelengths)
  3. Freeze/thaw state (surface, i.e. L-band)

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Soil moisture is on the water & energy cycle roadmap (as well as climate and weather roadmaps) because of its critical role in determining fluxes between the atmosphere and land. Knowledge of these should enable improved water budgets.
- This information should also be useful for carbon cycle modeling and determining whether some areas are sources or sinks of carbon.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Spatial resolution less than 1 km. Repeat times for overpass of a single area would be less than 3 days.
- Technique for resolving deeper soil moisture may not be employable from space without other technological advancements.
- Resolution of diurnal cycle.
- Sustained mission (>60 days) would begin to capture phenomenon over vegetation life cycles.
- Ability to compare phenomena across spatial scales.

Identify other cross-cutting areas impacted by this observation.

- Instrument & platform capability would be useful for sea surface salinity.
- Useful for biomass mapping
- Data useful to weather for antecedent conditions requirement.
- Validation capability for Orbital systems
- Risk mitigation for future <1km soil moisture measurement capability for NPOESS system requirement

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

1. Active/Passive microwave instrument having L and P bands and potentially longer wavelengths. Multipolarization and conical scanning desired.
2. Less than 200kg. Volume dictated by antenna size (antenna area required is 1-5 sq. meters).
3. Environmental considerations – could be limited to fair weather.
4. Power – depends upon instrument, 1-5 Kilowatts.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location – 40°S – 70°N
- Altitude – dependent on observation scale. Range of 1-10 km, but okay to go higher at times.
- Endurance and Frequency – duty cycle should be 70-80% of a week for "local" usage. For remote usage, require 24 hours, 2-3 times a week over target area, though using a "local" airport would help.
- Season – local spring-summer-fall in extra-tropics. All year in tropics.
- Single platform.
- Precise ground track knowledge required (<10 m). Control less important. Pointing accuracy for instrument needs to be <0.1 degrees.

- Geographic areas of interest would include all land areas, except those permanently covered by snow or ice.

Communication needs such as real-time data or instrument control

- Low data rate Housekeeping data (with back and forth communication) would be required.
- Real-time data not required for scientific research, however, information might be useful for real time decision makers so this capability might be required after instrument proves itself.
- Autonomy and pre-plan flight plans.
- High speed downloads required upon landing. Note that this would thus mandate sufficient data storage on board. Combine aircraft state data with instrument data, including time tags.

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- [Assumption is that this is a single aircraft entity. "day-in-the-life" might change were this a multiple platform mission.]

- Aircraft, instrument(s), and team members can go to host airport separately. Once there, instrument(s) would be integrated into the aircraft if not pre-integrated. Calibration flight(s) and resolution of anomalies would be required. Aircraft receives instructions for individual flight mission.

- Aircraft takes off and ferries to target location. At target, aircraft either makes circles over points or series of flight lines. This might include changing altitudes between circles/passes.

- Between sets of circles or passes the aircraft, sensor and mission control, go through a series of checks to determine if re-flying over a set area is required.
- Such as encountering error flags in data retrieval, strong crosswinds (location disruption), RFI errors, review of complimentary sensor data – which might require subsequent alteration of sensor specifications or flight paths.

- All signals from command control to aircraft while on route would be choices from a pre-set list of commands (or series of commands).

- Upon completion of programmed time period, or mission control signal, aircraft returns to host airport. Complete data (see above) is downloaded or removed rapidly from the aircraft. Aircraft is prepared for subsequent mission.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- This isn't really a critical component as flight profiles would be rather germane, e.g. simpler flight paths.

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

Identify any special or unique platform or mission issues

- As stated this "mission" concept is mostly to retrieve soil moisture information for research science. There are other abilities (of the UAV sensor tandem) that could be employed for other purposes. For example, giving soil moisture information to weather forecasters or doing floodplain mapping (essentially looking for very high soil moisture) these things would require extra requirements for UAV platform. For example, being able to re-program the fly path in mid-mission, or being able to download the information during mid-mission.

- This mission design would require new sensor development. This development would have to be done in concert with UAV and science priority evolution.

- This mission as defined here is mostly for UAV development to be used in "NASA Earth Science" first and "applications 2nd". If the UAV development should be directed to partner agencies, it would require some of the enhancements mentioned (real-time data download, changeable flight plans during the mission).

Summarize the key elements of the mission concept for this measurement.

- Ability to stay up for 24 hours and carry the active/passive system defined.

Water & Energy Cycles

Key Messages

- Ability for UAV's to do drop sondes or drop-buoys is exciting new potential… beyond bounds of what we would currently consider

- Science now requires routine, large-scale ubiquitous monitoring… Entails from the outset having better discussions with partnering Agencies… Other Agencies are ready for the data from observations we take almost as soon as we take it

- A large number of UAV's will be required for large-scale, ubiquitous monitoring or measurements, rapid response

- Need to do better work on developing roadmaps for the development and operation of both UAV's and instruments:
  - What is the life-cycle of these UAV's?
  - What are the off-ramps?
  - Need partnerships right from the very beginning
  - Even though we "pass off" UAV's to other Agencies, we may want them back at some point… We need "on ramps" to bring them back
  - Involve commercial entities in these partnerships as well

- Monitor the diurnal cycle… All parts of 24 or 48-hr. cycle… holds a lot of potential… Will help us make the next critical science breakthroughs

Weather

Attendees

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- Note: Robbie Hood (Lead)

Weather

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- Data void
  - Regions
    - Northwest Pacific
    - Eastern Pacific Arctic
    - Atlantic Ocean
    - Antarctic forecasting (research)

  Weather Phenomena
    Tropical genesis areas
    Process study
    Frontal systems
    Squall lines
  - Vertical, horizontal resolution

- Up-stream

- Variables

  - Temperature
  - Moisture
  - Winds
  - Pressure
  - Ozone
  - Aerosol Particle concentration
  - Precipitation
  - Electrical / Lightning
  - Cloud microphysics
  - Sea Surface Temperature and surface winds in hurricane
  - Soil Moisture (watershed resolution for agriculture)
  - Vertical velocity

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Chemical weather event (volcanoes, forest fires, sudden events)

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

Weather

Critical Science Questions

- Hurricane genesis, evolution, and landfall
- Targeted, adaptive observations
- Focused observations in extreme weather (squall lines, tornadoes, frontal systems)
- Forecast initialization in data sparse regions
- Chemical weather events (volcanoes, forest fires, sudden events)
- Cloud microphysics process studies

Weather – Cloud Microphysics / Properties

<u>Critical Observation</u>: Cloud microphysics/properties

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Measurements of turbulence, vertical velocity
- Particle size distributions, habit, phases
- Liquid/ice contents
- High accuracy thermodynamic information
- Electrical and radiation measurements
- Coordinated with higher altitude remote (or low altitude looking up) and/or satellites

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Key to observations of tropical rainfall and energy release
- Key to processes of rain particle growth
- Improvement of satellite algorithms
- (Stratospheric water exchange)
- *Caveats:
    - Build better forecast and retrieval schemes (vs. water and energy breakout)
    - Real-time parameterization

Explicitly state the advantage of using a suborbital platform for this measurement.

- Human safety
- High altitude aircraft and/or satellite
- Lower altitude

Identify other cross-cutting areas impacted by this observation.

- Water and energy
- Atmospheric composition
- Regional numerical weather models

Weather – Cloud Microphysics / Properties

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)*

- See Hurricanes for mothership

- On penetrating platforms (requires controlled descent and safe recovery at locations of opportunity, including automated landing site selection)
    - Microwave sensors (optional)
    - Particle size probes
    - Laser hygrometer
    - Radiation pyrometers
    - Electric field sensors/probes

- Hardened to severe environments (e.g. electrical, icing, turbulence)
- External pods
- Needs to be included under aircraft characteristics (no place in template for this)

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Penetrating platforms controlled by a higher altitude platform (e.g. mothership, perhaps including Scaled Composites' White Knight) or controlled by ground-based instrumentation (e.g. radars)
- Aircraft should be able to be launched (from another aircraft) and takeoff or land autonomously
- Coordinated flying of high altitude platform relative to penetrators
- Hardened to severe environments (e.g. electrical, icing, turbulence)
- Flight profiles – spiral or horizontal, with loiter capability in ice region
- Slow airspeed (~100 kts), but maneuverability against headwinds

Communication needs such as real-time data or instrument control

- See Hurricane mission for overall requirements
- Aircraft to aircraft high bandwidth/line-of-sight (LOS) or high bandwidth air-to-ground/LOS if controlled by ground-based radar
- Penetrators capable of different flight profiles, supervised by mothership or ground-based instrumentation
- On-board partial processing and telemetry

Weather – Cloud Microphysics / Properties

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Two scenarios:
  - Takeoff from existing runway, completes mission, and lands
  - Deployed from mothership, completes mission, and lands at sea or on land

- Aircraft readiness – near on demand (2-3 hrs)

- 20nm stacked, layered lines (horizontal) over 500nm range, maximum 5 hrs duration (assuming 100 kts TAS)

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

- Hardening
- Either spiral or horizontal
- Potential launch from mothership
- Coordinated with other remote sensing instrumentation

Summarize the key elements of the mission concept for this measurement.

- Coordinated flights with remote sensors

- Dangerous research mission (fly in the middle of a storm, but only means of observing cloud microphysics accurately)

- Potential operational applications for regional modeling and severe storm warning

Weather – Extreme Weather

<u>Critical Observation</u>: Focused observations – extreme weather

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Process studies involving severe and hazardous weather events to improve the physics in mesoscale models (parameterizations)

- High altitude remote sensing – precipitation, clouds, meteorological sounding, electrical, microphysics, dropsondes when possible (over ocean)

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Improve parameterizations for mesoscale models
  - Winter storm hazards determine at local levels for appropriate mitigation
  - Regional forecasting of rain and snow accurate for economic decisions

Explicitly state the advantage of using a suborbital platform for this measurement.

- Remote sensing measurements for long duration
- Human safety
- Higher spatial and temporal resolution sampling
- Continuous observation
- Long endurance and range
- Real-time telemetry and on-board processing (sensor web)

Identify other cross-cutting areas impacted by this observation.

- Numerical weather prediction
- Water and Energy Cycle
- Satellite validation (GPM, CloudSAT/CALIPSO, Aqua, NPOESS)
- Atmospheric composition (water vapor)

Weather – Extreme Weather

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- TYPE
  - *<u>High altitude platform</u>*
  - *Remote sensing sounder (temperature and water vapor)*
  - *Cloud and Precipitation radar and radiometer*
  - *Electrical and lightning*
  - *Dropsonde (when possible)*

- PAYLOAD CHARACTERISTICS
  - *<u>Payload weight</u>*
  - *Total payload ~1000 lbs*
  - *Power ~1-2 KW*
  - *No special considerations for environments*
  - *Sufficient downward viewing for radiometer and radar*
  - *Possible pod for dropsonde system*

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

LOCATION, ALTITUDE, ENDURANCE, ETC
- Mission guided by satellite and ground-based measurement systems
- Targeted and adaptive operation with real-time human intervention (mixed initiative)

AIRCRAFT
- <u>High Altitude Platform</u>
  - Altitude* - 15-20 km (depending on the event, needs to clear the storm tops with sufficient margins)
  - Temporal Coverage - Continuous coverage during life cycle of storm event (lagrangian)
  - Endurance/spatial Coverage – 200 km to 1500 km (depending on event), 1-2 days
- Multiple viewing areas and down-looking ports
- Single platform
- Readiness - Target of opportunity

- *Alternative out of the box thinking - Ultra-high altitude (e.g. 100K+ ft) observing location. This will affect instrument design and could serve as a suborbital satellite testbed.

Communication needs such as real-time data or instrument control

Weather – Extreme Weather

- Real-time telemetry and on-board processing (sensor web)
- 300 Kbits/second (eg. 1 –2 TDRSS size demand access channels)
- Real-time instrument control, low bandwidth
- Evolution to autonomous or supervised tracking

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Strategic decisions based on satellite and/or ground-based observations
- Adaptive release of microphysics sondes and dropsondes when possible
- Autonomous / semi-autonomous

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

(no input)

Summarize the key elements of the mission concept for this measurement.

- Process studies involving severe and hazardous weather events to improve the physics in mesoscale models (parameterizations)

- Improve parameterizations for mesoscale models
    - Winter storm hazards determine at local levels for appropriate mitigation
    - Regional forecasting of rain and snow accurate for economic decisions

Weather – Forecast Initialization

<u>Critical Observation</u>: Forecast initialization

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- <u>Research element</u> – Determining data sensitive regions (e.g. THORPEX, atmospheric rivers)

- <u>Operational/tech transfer pathway</u> - e.g. NOAA/NCEP winter storms program

- <u>Short term – 24 hr initialization (events already formed)</u>
- Event oriented, fly ocean regions
  - Eastern Pacific (as an example)
  - Northern Atlantic
  - Arctic/Antarctic
- With remote sensing instruments/in-situ and high resolution vertical profiling (beyond satellites), including assimilating satellite data

- <u>Longer term – 3-7 day (running forecast models backwards)</u>

- <u>Satellite validation (e.g. GPM and GIFTS Validation, improved use of satellite for forecasting)</u>

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Supports NASA/NOAA collaborative centers and high resolution global measurements

Explicitly state the advantage of using a suborbital platform for this measurement.

- Cannot/may not be able to obtain necessary vertical resolution from satellites

Identify other cross-cutting areas impacted by this observation.

- Global water and energy cycle
- Climate observations
- Supports Other Government Agencies (e.g. NOAA, FEMA)

Weather – Forecast Initialization

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Same as Hurricane (mostly high altitude)
- <u>Payload weight</u>
- Total payload ~1000 lbs (e.g. radiometer(s) ~100 lbs, radar ~150 lbs, wind lidar ~300 lbs, FTIR ~100 lb, dropsondes)

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Same as Hurricane, but slightly lower altitude (50K ft, region dependant).

Communication needs such as real-time data or instrument control

- Same as Hurricane

Weather – Forecast Initialization

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Launch one or more suborbital platforms to begin/develop circuit.
- Real-time re-tasking of one or more platforms out of circuit to sensitive zones.
- Deployment of expendable or reusable/redockable sondes at regular and special locations/times.
- Real-time data assimilation into forecast models

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Baseline circuit (10K km long, sampling low/high density regions ~20-200 km) with adaptive vectoring to sensitive regions, such as fronts (grid search).

- Time-criticality
    - Need to complete grid in 1/2 day (speed dependant, enhanced via model-based decision support (e.g. OSSI/E))

- Total circuit – several days

Identify any special or unique platform or mission issues

- Redockable daughtership
- Long distance and endurance (above severe weather)

Summarize the key elements of the mission concept for this measurement.

- <u>Research element</u> – Determining data sensitive regions (e.g. THORPEX, atmospheric rivers)
- <u>Operational/tech transfer pathway</u> - e.g. NOAA/NCEP winter storms program

- <u>Short term – 24 hr initialization (events already formed)</u>
- Event oriented, fly ocean regions
    - Eastern Pacific (as an example)
    - Northern Atlantic
    - Arctic/Antarctic
- With remote sensing instruments/in-situ and high resolution vertical profiling (beyond satellites), including assimilating satellite data

- <u>Longer term – 3-7 day (running forecast models backwards)</u>

Weather – Hurricane Genesis, Evolution, and Landfall

Critical Observation: Hurricane genesis, evolution, and landfall

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- High altitude remote sensing – precipitation, clouds, meteorological sounding, electrical, microphysics, dust

- Tropospheric – 4-D data cubes of thermodynamic variables and winds in (in situ microphysics)

- Boundary Layer – sea surface temperature and surface winds, surface imaging, turbulent fluxes, surface state (wave spectra, sea spume, etc,)

Explicitly state how this observation and measurement supports this Earth Science focus area.

(no input)

Explicitly state the advantage of using a suborbital platform for this measurement.

- Human safety
- Higher spatial and temporal resolution sampling
- Continuous observation
- Long endurance and range (access to sparsely sampled regions)
- Multi-platforms and constellation flying
- Real-time telemetry and on-board processing (sensor web)

Identify other cross-cutting areas impacted by this observation.

- Water and Energy Cycle
- Satellite validation (GPM, CloudSAT/CALIPSO, Aqua, NPOESS)
- Numerical weather prediction
- Atmospheric composition (water vapor)

Weather – Hurricane Genesis, Evolution, and Landfall

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

TYPE

- <u>High altitude Platform</u>
    - Meteorological sonde instruments (in situ)
    - Dropsonde (meterological)
    - Remote sensing sounder (temperature and water vapor)
    - Cloud and Precipitation radar and radiometer
    - Electrical and lightning
    - Surface wave spectra (GPS reflectance, lidar)
    - Visible imaging for eyewall (Rossby waves)
    - Profiling lidar

- <u>Tropospheric</u>
    - Dropsondes
    - (Microphysics)

- <u>Boundary layer</u>
    - Infrared pyrometer (SST)
    - In situ winds (new instrument development)
    - Surface imaging (visible)
    - Turbulent fluxes (new instrument development)
    - Meteorological sonde instruments (in situ)

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- LOCATION, ALTITUDE, ENDURANCE, ETC
    - Target tropical cyclone by ocean basin
    - One storm at a time (testbed demonstration)
    - Aircraft assets (minimum – 1 high altitude, 2 tropospheric, 5 boundary layer)
    - Adaptive flight formation guided by satellite and high altitude aircraft
    - Autonomous operation with real-time human intervention (mixed initiative)

Weather – Hurricane Genesis, Evolution, and Landfall

- AIRCRAFT
  - High Altitude Platform
  - Altitude - Above 20 km (tradeoff with field of view)
  - Temporal Coverage - Continuous observations for two weeks (single or multiple sorties/platforms)
  - Spatial Coverage – 200 km to 1500 km
  - Multiple viewing areas and down-looking ports
  - Dropsonde
  - Smartsonde
  - Daughter ship (expendable or redockable)

- Tropospheric
  - Altitude – 6-12 km
  - Temporal Coverage - Continuous observations after genesis
  - Spatial Coverage – 200 km to 1500 km
  - All weather performance during lightning, icing, graupel, turbulence
  - Dropsonde
  - Smartsonde
  - Daughter ship (expendable or redockable)

- Boundary Layer
  - Altitude – 100m to 6 km
  - Temporal Coverage – Continuous observations for two weeks (multi-aircraft)
  - Spatial Coverage - 200 km to 1500 km

Communication needs such as real-time data or instrument control

- Real-time telemetry and on-board processing (sensor web)
- 300 Kbits/second (eg. 1 –2 TDRSS size demand access channels)
- Real-time instrument control, low bandwidth
- Wideband, line of sight communication link for multi-platform network
- Evolution to autonomous or supervised tracking

Weather – Hurricane Genesis, Evolution, and Landfall

Mission Concept: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a “day-in-the-life” of the mission.

- Formation flying
- Adaptive release of sondes or daughter ships
- Autonomous / semi-autonomous
- Decision support tools leading to autonomous operations

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

(no input)

Identify any special or unique platform or mission issues

- Hi-band Communication
- Redocking or recoverable
- Daughter ship
- Controlled, reusable sondes

Summarize the key elements of the mission concept for this measurement.

- Formation flying in 3 altitude ranges
- Adaptive flights
- Mother/daughter ship
- Redockable or recoverable
- Autonomous tracking

Weather

Key Messages

<u>Key Metric:</u>

- Forecast improvement

<u>Key Tasks:</u>

- Bridge the gap between research/process studies and operational applications

<u>Key capabilities:</u>

- Real-time data downlink
- High resolution
- Cutting-edge remote sensors/platforms
- Adaptive, event-driven observations (hurricanes, winter storms, flooding); regional events

<u>Key activities:</u>

- Research
  - Downward-looking capabilities
  - Real-time high resolution data down-linking data capabilities
  - Process studies
    - What observations/assimilation are important
    - How to interpret them
    - Parameterization/applications

- Operational transfer
  - Partnerships (e.g. SPoRT, Joint Center)
  - NASA technology contributing to forecast improvements

*Still wish to solicit additional input from others in the broader weather community (e.g. modelers)

Miracles

"It would be a miracle if we had the technology that would enable …."

Solid Earth- Miracles:

- Rubles, shekels, gold
- SUB MILLIMETER POSITIONING ACCURACY
- BROAD BAND DATA LINKS- Multi-Mb/s-over the horizon
- Light weight high bandwidth large volume (TB) storage
- Small volume high accuracy (microgal) gravity gradiometer
- Accurate low cost gyros and accelerometers
- Sub arcsecond attitude measurement
- Autonomous precise (sub meter) formation flying
- Lightweight antennas
- Rapid transit to sites (400 knot) with slow speed acquisition (100 knots)
- Spatial separated mount points with significant mass and volume capacity

Brainstorm list:

- Sensor Web: If suborbital could be leaders in developing a sensor web so scientists, students, the public – everyone – can get the data from satellites, suborbital and ground-based sources; everyone can get to it quickly and easily; they can grab what they want and tailor it to their use
- Reduced flight cost: fly for 10,000 hours; get cost/flight hour down
- Traditional way of looking at flight cost should not apply to these mission concepts
- "Indy 500" type system for UAV's: They come into the "pit", we slap everything new on, pull one payload off, put new one on, and put it right back in the air
- Standardized interfaces for data systems and sensors… interchangeable, flexible (goes with "Indy 500")
- Measure bathimetry – geometry of channels in/and rivers
- Fly through severe weather
- Meter-scale tropo water vapor measurements – remotely
- Penetrate the oceans at 10,000 ft. – remote sensing (same for land)
- Operation by extremely small crew numbers (ideally crew of 1 or 0); Controlled from joystick or mouse – complete automation
- Effectively permanent flight (3 months) – a "roving satellite"
- Daughter ship concept – deploy, descend, and re-dock from mother ship

Miracles

- Near-expendables – small aircraft, if they're lost it doesn't matter; they may be recovered but they are not critical; Many for multi-point measurements
- Illustrated roadmap: how we're going to get where we're going from where we are… what it's going to cost… when we're going to get there
- Significantly miniaturized instruments
- Very tight formation flying
- Very high precision pointing accuracy for optical communication and energy transmission
- Ability to beam energy to different platforms using microwave (remotely powering platform)
- Pointing accuracy for high-altitude Lidar
- Navigation in hurricanes and severe convection, electrical, icing, wildfires, updrafts, etc. – extreme conditions
- Unrestricted operations in national (international?) airspace
- Very small sense-and-avoid systems
- Small size memory for data storage
- Unrestricted spectrum (frequency)
- Very high bandwidth in polar regions (long range)
- "Returnable bottles": Sensors so small and so cheap you can go out in the field with a dozen in your back pack… if you bring them back fine; if not, you can get new ones
- Standardized data archive system
- My own platform
- Sensor packages embedded into existing world transportation system
- Journal of Geophysical Research to go back to its old citation format
- Autonomy to the level of doing group strategic goals: a number of airplanes flying together to accomplish a mission, with the smarts on board to follow what they want
- System-level integration (satellite, suborbital and ground-based)

Key Messages

What are the key messages from this Science Focus Area?

Atmospheric Composition

- Tailored improvements to UAV developments currently underway at orders of magnitude higher funding levels (i.e., Global Hawk)
  - Revolution is disruptive
  - Maintains continuity with existing capabilities

- Expansion of existing envelope rather than definition of entirely new envelope with limited funding
  - Increased range, duration, payload capacity, geophysical performance
  - Ensure that science drives UAV technology modifications rather than aeronautic technology seeking scientific justification

- Parallel / well-funded instrument development program is essential. Maintain and evolve core research and analysis

- Maintain complete observation system synergy
  (satellite – suborbital – ground – models)
  - Unique elements to each
  - High complementarity
  - Sensor web requires all components

- Show us some concrete results from this workshop
  - Not just paper
  - We've been here before

- Explore national and international cooperation and partnerships

Key Messages

Carbon Cycle, Ecosystems, and Biogeochemistry

- We need high-quality hyperspectral thermal suborbital sensors
- Quality of sensor is tantamount – including stability over time
- We need low-and-slow as well as high-and-slow platforms
- Radar / 3D mapping capabilities (LIDAR)
- Fluorescence imaging
- Diurnal cycle observations
- Improved data mining / data fusion
- ID and long-term observations of source / sink instabilities
- Sea-land, sea-air, land-air – remote flux measurements
- Flask sampling from UAV's
  - Consituent sampling for all important biological gases
  - Continuous stream
- High precision GPS and pointing
- All different classes of platforms
- Contemporaneous phasing of instruments and platforms and science (co-evolution)
- Improved data user interface and rapid delivery (near real-time)
- Contemporaneous measurements of passive and active are important
- Better qualification of biomass combustion
- There are many timescales that are important in addition to diurnal – seasonal, annual and interannual

Key Messages

Climate Variability and Change

Climate data grows in value with time, and requires data of sufficient quality to determine small trends that increase in importance with time. This implies the need to implement the 20 Climate Observing Principles of App 12.4 of the CCSP Strategic Plan. There is little precedent for obtaining climate quality data over extended periods from suborbital platforms. To achieve this quality routinely with aircraft will require new approaches in regard to aircraft performance, planning and execution of missions, and payload instrument performance. Aircraft will be required to stay aloft for extended periods with minimal maintenance time on the ground, have range and duration to cover a large fraction of the globe, and have facility for remote control of flight plan and flight track. Instrument requirements include greater precision and calibration stability, and reduced cost to facilitate the availability of multiple units in field deployments. Future ready availability of multiple reliable UAVs will allow meeting of unique climate needs.

Climate observing needs:

1. Need for many 1000's of hours of annual flight time over many years, for thorough sampling of climate variability and climate change. Implies different experimental regimes -- long duration, 3-d sampling, large volumes, many repetitions over climate time scales. E.g., month-long campaigns in each of several years. Also implies low cost per flight hour, fewer required personnel, reliability and maintainability. Need environmentally friendly and system friendly platforms (engine, vehicle, airspace, etc).

2. Development of instruments for difficult-to-observe parameters (e.g. polar ice thickness, subsurface ocean temperatures and salinity, precipitation). The development needs to consider potential applications on and integration with suborbital platform systems (pointability, formation flying, etc.), and the orbital, suborbital, ground-based, and subsurface system-of-systems.

3. Adaptable and readily deployable systems for climate quality observation of abrupt climate changes.

4. Onboard calibration and monitoring, thorough instrument characterization, high engineering quality systems.

5. Coordination with overflying satellites for validation of retrieval algorithms;

6. Large, reliable, longterm, easily accessible archival system.

Key Messages

Earth Surface and Interior Structure

<u>Issues of Importance to the Earth Surface and Interior Focus Area:</u>

1. UAV/OPV will provide high resolution continuous 4-D observations that will not be available from spaceborne platforms for 10-15 years minimum

2. Because of natural attenuation of geopotential fields, UAV's can provide high spatial and temporal resolution observations not possible with satellites. High altitude UAV measurements provide quiescent observations needed for ultra high sensitivity measurement of the gravity field and will fill spectral gaps between geopotential satellite observations and national and commercial near surface studies.

3. Reconfigurability and adaptability of UAV's to instruments is an important enabling feature such as in radar applications where aperture design is an issue.

Across Focus Areas

4. Access to international airspace (airspace of other nations) for UAVs is a critical issue-an argument for OPV availability in the near term.

5. Need OPV as transition to UAV for the development of instrument technology, exploration capability, and algorithms.

6. Readily accessible low cost UAV fleet will provide important and valuable development platforms for rapid concept development and testing.

Key Messages

Water & Energy Cycles

- Ability for UAV’s to do drop sondes or drop-buoys is exciting new potential… beyond bounds of what we would currently consider

- Science now requires routine, large-scale ubiquitous monitoring… Entails from the outset having better discussions with partnering Agencies… Other Agencies are ready for the data from observations we take almost as soon as we take it

- A large number of UAV’s will be required for large-scale, ubiquitous monitoring or measurements, rapid response

- Need to do better work on developing roadmaps for the development and operation of both UAV’s and instruments:
  - What is the life-cycle of these UAV’s?
  - What are the off-ramps?
  - Need partnerships right from the very beginning
  - Even though we “pass off” UAV’s to other Agencies, we may want them back at some point… We need “on ramps” to bring them back
  - Involve commercial entities in these partnerships as well

- Monitor the diurnal cycle… All parts of 24 or 48-hr. cycle… holds a lot of potential… Will help us make the next critical science breakthroughs

Key Messages

Weather

<u>Key Metric:</u>
- Forecast improvement

<u>Key Tasks:</u>
- Bridge the gap between research/process studies and operational applications

<u>Key capabilities:</u>
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  - Partnerships (e.g. SPoRT, Joint Center)
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*Still wish to solicit additional input from others in the broader weather community (e.g. modelers)

Key Messages

Key Themes across Science Focus Areas

- Maintenance of current capabilities is critical to achieving a revolution to new technology
- We need multiple platforms and multiple sensor capabilities – an integrated system
- We need a parallel effort to develop instruments along with suborbital platforms
- We need the capability to respond to events over geophysical timescales that are consistent with the events we're trying to measure
- We have the instruments and the need to use UAV technology *right now*
- Keep and eye out for the low-and-slow mission – There are needs right now; The missions are likely to be terrestrial (over land and ice observations will likely be a priority in the Carbon focus area)
- Partnerships are critical – national and international
- Access to national and international airspace is critical
- We need to consider a maintenance program for new technologies
- There is a lot of synergy between suborbital assets and satellites, ground based, subsurface, modeling, etc. – opportunity to establish a "Sensor Web"
- There is need is for affordable flight hours – many hours over many years
- Real-time availability of data is a key interest

Insights Emerging from the "Products"

- A variety of aircraft from daughter ships to big buses
- A lot of autonomy and interaction between platforms leading to sensor web and planetary exploration applications
- Parallel instrument and payload development is critical to future mission success

Next Steps

- **Monday, July 19** - Cheryl sends out workshop package to participants
- **Friday, July 23** – Science Focus Group Leads complete whatever coordination they want with their respective communities and send final package by COB (EDT) to Cheryl, Randy, and Cathy
- **Friday, July 30** – Randy posts final proceedings to Suborbital Science website
- **Friday, July 30** – Randy will turn over final templates to Aeronautical Engineering Team headed by Chris Nagy
- **August 3-4** – Cheryl, Randy and John Sharkey will preview highlights of this workshop at the Interagency Workshop on UAV Collaboration (NASA, NOAA, DoE – to identify science drivers for UAV technology investment);
- **August** – October – Ongoing dialogue and collaboration between engineers and Science Focus Groups (coordinated through Group Leads)
    - **September 19** – AIAA UAV Conference in Chicago
    - **October** – UAV Conference in New Mexico
    - Contact Randy if you want engineering community to brief or participate in ongoing science team meetings
- **October** – Chris Nagy provides preliminary Suborbital Technology Roadmap
- **January / February 2005** – Suborbital Science Program’s Winter Program Review provides opportunity for formal feedback and validation
- **Ongoing annual cycle** of planning and collaboration

Closing Remarks

John Sharkey

- We've received a lot of excellent inputs and mission concepts
- It has been very stimulating for the engineering community to hear those requirements… to consider how to translate those "miracles" into mission plans
- I also heard a validation of the current plan… We didn't hear that the path we're going down is inappropriate… The message has been that it's good but not sufficient
- Heard a validation that high-altitude, long-endurance is needed and we should continue
- Global observer, autonomy work, formation flying, precision trajectory… these still seem to be valid inputs
- A few small gaps that showed up here – low-and-small, daughter ships… there are technical solutions for those… we can incorporate those into roadmaps
- One big gap is the programmatic alignment and funding for the platforms and instruments…
- Another big gap is budget integration with satellite programs
- Roadmaps will be worked…
- I would expect to see roadmaps at the end of FY '05
- Following August workshop, do a joint presentation of this effort and the Scripps workshop… to Al Diaz, Vic LeBacqz, and Ghassem Asrar… in late August

Cheryl Yuhas

- Thank you for coming and participating as effectively and enthusiastically as you have
- In the annual review there will be formal feedback to you on our accomplishments
- Besides telling you what we're doing in new technology platforms, we will be expanding the whole suborbital requirements process to all suborbital platforms – including traditional, manned platforms
- If you have any comments and/or recommendations please call me or any of the core team

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